A METHODOLOGY FOR OPERATIONALIZING SUSTAINABLE RESIDENTIAL DEVELOPMENT

By

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by

Kevin R. Grosskopf

The dedication of this dissertation is devoted to my wife, Tammy Diane Grosskopf, whose unending support and encouragement as a wildlife ecologist provided me the impetus to further this work. Placing the preservation of the environment and the protection of the voiceless above her human ordained right to exploit them, Tammy will forever command my deepest respect, love and admiration. The personal sacrifices which I have imparted to Tammy as a result of 3 years of our lives spent apart on this endeavor are irreplaceable. Please find it in your heart to forgive me for all that has happened during this difficult time.

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KEY TO SYMBOLS

Economics

i	interest rate
n	time, number of compounding periods
r	discount rate, inflation

Statistics

N	number of subjects in a population
n	number of subjects in a sample
ρ	proportion; probability level, alpha level of significance
α	alpha level (Type I error rate)
X	independent variable (IV)
Y	dependent variable (DV)
f	frequency, number in a group or at a score
Σ	sum of , summation
σ	standard deviation (interval scale)
σ^2	variance (interval scale)
X	score
r	Pearson product moment correlation (interval scale)
df	degrees of freedom
X^2	chi-square test (nominal scale)

Thermodynamics

Q	heat (flux)	$Btu/hr*ft^2$
C	conductance	$Btu/hr*ft^2*^oF$
R	resistance	$hr*ft^2*^oF/Btu$
U	overall heat transfer coefficient	$Btu/hr*ft^2*^oF$
k	conductivity	$Btu/hr*ft^2*^oF*in$
ΔT	difference in temperature	^oF

KEY TO ABBREVIATIONS

ACQ	Alkaline Copper Quat
AHERA	Asbestos Hazard Emergency Response Act
ANOVA	Analysis of Variance
ASTM	American Society for Testing Materials
Btu	British Thermal Units
CBA	Cost-Benefit Analysis
CCA	Chromated Copper Arsenate
CCR	Capital Cost Recovery (syn. "break-even point")
C&D	Construction and Demolition
CDD	Cooling Degree Day
CDH	Cooling Degree Hour
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	Chlorinatedfluorocarbon
CIP	Cast-In-Place
COTS	Commercial off the shelf
CMU	Concrete Masonry Unit
CSI	Construction Specifications Institute (categorization format)
DEP	Department of Environmental Protection (State of Florida)
DV	Dependent Variable
EPA	Environmental Protection Agency (U.S.)
EV	Extraneous Variable (syn. Intervening Variable)
FAC	Florida Administrative Code

GNPP	Global Net Primary Production
HDD	Heating Degree Day
HRS	Health and Rehabilitative Services (State of Florida)
IV	Independent Variable
IQ	Irrigation Quality
k	Thermal Conductivity
K	Thousand
LCA	Life-cycle Cost Analysis
MARR	Minimal Attractive Rate of Return
NLB	Non-Load Bearing
NAHB	National Association of Home Builders
NIC	Newly Industrialized Countries
PCB	Polychlorinatedbyphenol
QUADS	Quadrillion Btu, 10^{12}
RCRA	Resource Conservation and Recovery Act
RIC	Rapidly Industrializing Countries
ROI	Return on Investment
R/R	Runoff/Retention (stormwater reuse)
SAS	Statistical Analysis System
SHGC	Solar Heat Gain Coefficient
SIR	Savings-to-Investment Ratio
SPSS	Statistical Package for the Social Sciences
TSDF	Treatment, Storage, and Disposal Facility
VOC	Volatile Organic Compound
WHO	World Health Organization (United Nations)

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A METHODOLOGY FOR OPERATIONALIZING SUSTAINABLE RESIDENTIAL DEVELOPMENT

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Recognizing the linkages between the natural, social, and economic systems in qualitative terms, *life-cycle cost models* assessing the energy and water resource minimization performance and subsequent economic return on investment (ROI) of more than fifty interdependent sustainable alternatives were developed. A range of ROI variance for each alternative was calculated by manipulating projected energy and watergy interest and discount rates. The range of life-cycle ROIs for each alternative was then compared to *market survey assessments*, which modeled the consumer minimal attractive rate of return (MARR). Data sets were generated to compare and contrast the market elasticity for sustainable alternatives, categorized by capital cost recovery (break-even point) at 10, 15, 20 and 25 year intervals and ordered within each category by savings-to-investment ratio (SIR). Finally, a decision analysis matrix was then constructed using the data sets from the life-cycle cost models and market survey assessments to select sustainable alternatives based on regional economic, climatic and demographic criteria. The intent of the decision matrix was to satisfy an industry need for a simple "score-card" that would allow home building professionals to efficiently select marketable alternatives without cost intensive value-engineering analysis.

The population chosen for this study is owner-occupants of new single-family detached housing constructed since 1990 in Jacksonville, Orlando and Miami, representing "high-growth" regions of north, central, and south Florida. The immediate metropolitan areas of Jacksonville, Orlando and Miami represent 44% of the State's 14.5 million residents and more than 50% of its owner-occupants. Florida is the 4th most populated state with the 2nd highest net growth rate in a nation that represents 5% of the world's population but 20% or more of its resource consumption (29, 41).

CHAPTER 1
FORMULATION AND DEFINITION OF PROBLEM

Contribution

This research provides, for the first time, a methodology to operationalize sustainable residential development by providing tools for assessing the market potential of "green" technologies in single-family housing. The major contribution is a methodology for determining the extent to which capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable alternatives. This research determined the life-cycle ROI variance for several alternatives and compares this data to the consumer minimal attractive rate of return (MARR). The market elasticity for sustainable alternatives was calculated and a decision analysis matrix constructed to provide building professionals an effective method for selecting marketable alternatives.

Problem Statement

Sustainability can be defined as a means of profiting from the "interest" or regenerative capacity of the environment and not its interest-bearing capital stocks. Operationalizing this concept in residential development requires practices that reduce the use of non-renewable resources, the generation of waste and the overuse of energy and "watergy" (water and energy) resources, during both the development process and throughout the building life-cycle. U.S. industries creating and supporting the built environment contribute 8-10% to the annual GNP and remain a leading indicator of the nation's economic well-being. Yet to be sustainable, an industry that derives nearly all its material wealth from natural resources and employs between 8-10 million people must now complement traditional development criteria with a new set of principles that address the ecological impacts of human activities. In Florida, where nearly 50% of the State's 14.5 million people reside in 3 metropolitan areas, resource depletion is expected to reach a crisis level unless sustainable patterns become reality. To materialize in a free-market economy however, it is postulated that sustainable development in Florida must be driven by market-based solutions and not solely by government regulation. Yet to determine the extent to which current markets exist for sustainable alternatives, the life-cycle cost-benefit of each alternative must first be modeled. Secondly, the consumer response to the cost-benefit of sustainable alternatives must be assessed.

Philosophical Framework and Basic Assumptions

Although many within the sustainability movement have addressed resource economics using complex theoretical models and futuristic frameworks, few have yet to produce a practical model that assesses the economic and social transition from traditional development to sustainable development today. This research is based on the assumption that sustainable development is a transformation of current-state social and economic systems; not a "quantum leap" to utopia dependent on unrealistic or unquantifiable conditions. As a result, this research is intended to contribute to the early stages of this transformation, as society moves from a supply and demand (capital cost) economic system that externalizes the cost of many adverse impacts to the environment, to one that begins to internalize the costs of human use of the ecosystem into a market-based (life-cycle cost-benefit) incentive system. The result of this beginning stage "full cost" transformation may not ensure a means for all future societies to live within the regenerative capacity of the environment and distribute all the world's resources in an equitable fashion. This research merely contributes a foundation for the development of future economic structures to better account for tomorrow's environmental realities.

The supply and demand system is based on accruing wealth from low entropy natural stocks sold as capital investments, used within the human development system, and returned as high entropy waste. This linear path discounts the value of "once" used resources, allowing the extraction of non-renewable and renewable resources above rates of regeneration to be more economically viable than sustainable harvesting. As a result, this economic system promotes unbridled growth beyond the carrying capacity of the environment. The law of diminishing returns suggests that this system will ultimately fail as more natural capital is spent attempting to defend or gain access to fewer remaining natural resources.

The basic assumption of this research is that economic systems must begin to assess the full cost of resource consumption and subsequent waste generation and internalize this cost back to the economic and social systems. Although the "full cost" may be unquantifiable today, patterning economic and social system structures based on what is currently known about the cyclic, life-cycle efficiency of the natural system is a logical first step. This circular flow will result in products that are more resource efficient, creating the most productive yield while generating the fewest waste by-products. Price structures for virgin resources, especially non-renewable resources, will promote an investment in human capital and less investment in natural capital, which under the current supply and demand system, is often used to finance the accelerated exploitation of more distant, dilute natural resources.

In the context of the built environment, moving from "externalizing" supply and demand systems to "internalizing" economic structures involves the establishment of criteria that assess the ecological impacts of building alternatives. Those energy and "watergy" alternatives that promote clean air and water, reduce the withdrawal of resources and the discharge of wastes, reduce habitat destruction, promote bio-diversity and stabilized climate are considered more ecologically sustainable than conventional alternatives. *Watergy includes those alternatives that reduce both energy and water resource consumption.* Once a sustainable criterion is derived, sustainable alternatives can be selected based on the resource minimization performance of each over a conventional alternative by comparing life-cycle cost-benefits and associated returns on investment (ROI) to first-costs and capital investments. Life-cycle costs refer to the total cost of an energy or watergy alternative amortized and discounted over its useful life. Life-cycle cost modeling may reflect differences in performance "payback" such as hard-costs (i.e., durability, efficiency, maintenance, replacement cost, disposal fees, etc.) and soft-costs (i.e., health effects, opportunity costs, etc.) discounted back to the consumer. Optimization models can then identify initial cost saving alternatives as well as "break-even" points where higher first-cost sustainable alternatives provide a ROI over conventional alternatives using varying amortization and discounting rates. The life-cycle performance and cost-benefit results can be compared to consumer metrics, such as demographic dependent MARR and willingness-to-pay. Once completed, positive and negative correlations between the quantified life-cycle cost-benefit modeling can then be compared to the qualified market assessments forming the basis for a decision analysis matrix. The matrix can then be used to satisfy an industry need for a simple predictive "tool" that would allow home building professionals and developers to efficiently select marketable alternatives without cost intensive value-engineering analysis. Figure 1.1 above illustrates the primary boundary conditions and approach of the research to follow.

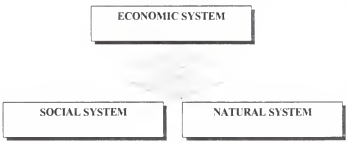

Figure 1.1. Natural, social and economic system life-cycle cost-benefit interface.

Research Questions

Primary Research Question

To what extent will capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives?

Research Scope, Purpose and Objectives

During 1995-96, the University of Florida Center for Construction and the Environment established the first sustainable criteria for planned communities in the State of Florida. The criteria were implemented during the formative design stages of a 2,050 acre residential community called "Abacoa." In the actual implementation, no sustainable energy and watergy alternatives with higher capital costs were selected due to the lack of detailed, integrated ROI information necessary to stimulate consumer interest. Correspondingly, no market analysis was available to determine the MARR needed to stimulate consumer interest. As a result, an innovative development plan that had every intention of soliciting market interest in sustainable residential development could do little to further the sustainable initiative without key life-cycle cost-benefit or consumer MARR data. The purpose of this research, therefore, is to assess the life-cycle resource minimization performance and cost-benefit of sustainable residential development and to provide market assessments that will determine positive and negative correlations between current economic resource valuation and consumer minimal attractive rates of return. The following research objectives define the approach used to achieve this goal.

Objective I - Life-cycle Cost Modeling

- Determine optimal energy and watergy alternatives based on maximum return on investment (ROI_{max}) at five (5) year capital cost recovery (CCR) intervals to 25 years.

Objective II - Market Survey Assessments

- Determine the effect of life-cycle ROI, the independent variable (IV) on consumer response, the dependent variable (DV) to sustainable energy and watergy alternatives.

Objective III - Decision Analysis Matrix

- Develop a matrix from the life-cycle ROI and consumer response models to provide a predictive "tool" allowing building professionals to select marketable energy and watergy alternatives.

Research Population

In 1996, residential communities accounted for 33% ($103.6 billion) of all new construction in the U.S. and the single largest share of the built environment.(58) In Florida, a state that is the 4th most populous (15.3 million by 2000) and 2nd fastest growing (1.1 million, 1995-2000) in the U.S., single-family housing (1,500 square feet mean) represents 3.1 million total units and 4.7 billion ft^2 total residential floor area (11,29). A stratified sample frame was drawn from this general population for life-cycle cost modeling and market survey assessments and was limited to the following research parameters:

- Single-family detached housing units (<2,500sf gross floor area) constructed since 1990.
- Sustainable energy and watergy alternatives within the building envelope of residential "case-studies" representing single-family detached dwelling stock in Florida.
- Owner-occupants of single-family detached housing units within high-growth residential regions in north, central and south Florida.
- High-growth regions of Jacksonville, Orlando and Miami representing major climatic and demographic areas of north, central and south Florida.

The stratified population defined above was treated as a single aggregate entity, representing 44% of State's 14.5 million population and more than 50% of its residential owner-occupants.

Research Methodology

The primary contribution of this dissertation is its methodology, a descriptive-correlational research design that attempts to determine the extent to which capital costs and life-cycle return on investment (ROI) affect consumer willingness to pay for sustainable alternatives. The assumption is made that sustainable residential construction, a first-level dependent variable (DV_1) is affected by market-consumer response, a first-level independent variable (IV_1) and first-level extraneous variables (EV_1) such as regulatory and institutional influences. This assumption was not the primary focus of research and was not directly tested. The effects that capital and life-cycle costs, second-level independent variables (IV_2) have on market-consumer response to sustainable construction was the focus of this research and was tested while controlling for second-level, non-cost related extraneous variables such as early adoption, perception and aesthetics (Figure 1.2).

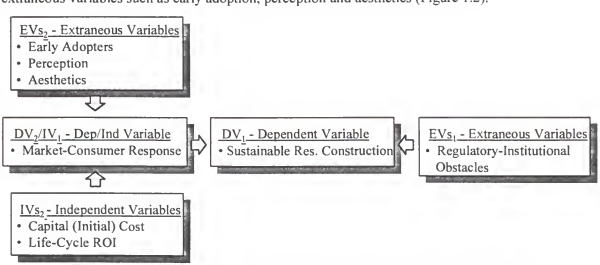

Figure 1.2. Major independent, dependent and extraneous variables of study.

The following diagrams (Figures 1.3 and 1.4) provide a logic sequence developed to identify the scope of research and establish the necessary boundary conditions for research. The diagram begins with a sequence of background (secondary) research milestones that refine the broad research area into a specific, tractable problem. The (primary) research methodology, or the contribution to the body of knowledge, is given direction with the statement of the research questions and objectives.

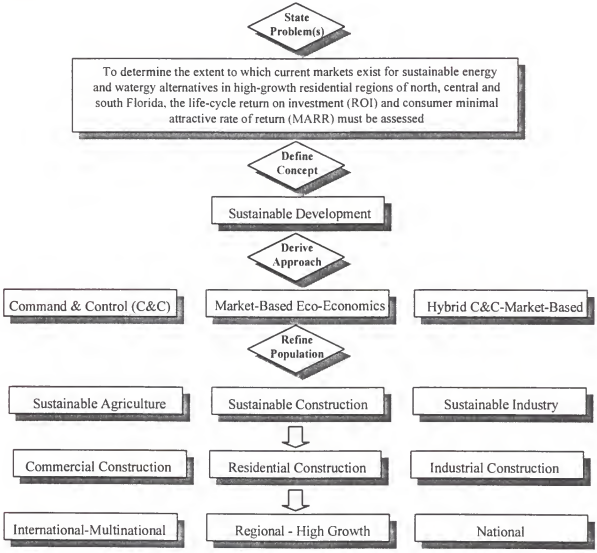
State Problem(s)
To determine the extent to which current markets exist for sustainable energy and watergy alternatives in high-growth residential regions of north, central and south Florida, the life-cycle return on investment (ROI) and consumer minimal attractive rate of return (MARR) must be assessed
Define Concept
Sustainable Development
Derive Approach
Command & Control (C&C)
Market-Based Eco-Economics
Hybrid C&C-Market-Based
Refine Population
Sustainable Agriculture
Sustainable Construction
Sustainable Industry
Commercial Construction
Residential Construction
Industrial Construction
International-Multinational
Regional - High Growth
National

Figure 1.3. Research background.

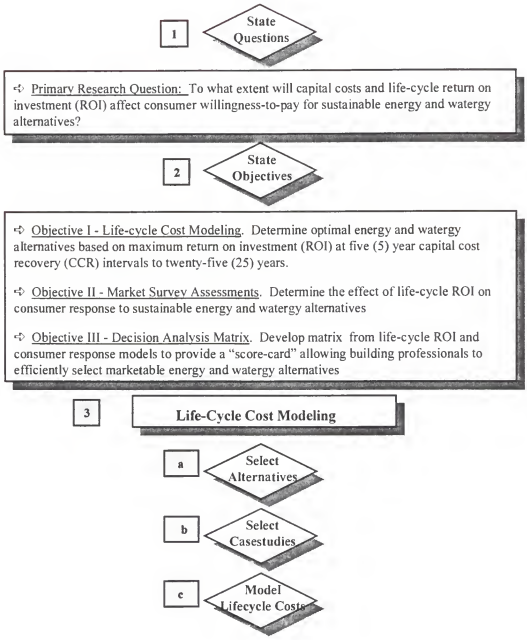
1
State Questions
➪ Primary Research Question: To what extent will capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives?
2
State Objectives
➪ Objective I - Life-cycle Cost Modeling. Determine optimal energy and watergy alternatives based on maximum return on investment (ROI) at five (5) year capital cost recovery (CCR) intervals to twenty-five (25) years.
➪ Objective II - Market Survey Assessments. Determine the effect of life-cycle ROI on consumer response to sustainable energy and watergy alternatives
➪ Objective III - Decision Analysis Matrix. Develop matrix from life-cycle ROI and consumer response models to provide a "score-card" allowing building professionals to efficiently select marketable energy and watergy alternatives
3
Life-Cycle Cost Modeling
a
Select Alternatives
b
Select Casestudies
c
Model Lifecycle Costs

Figure 1.4. Research methodology.

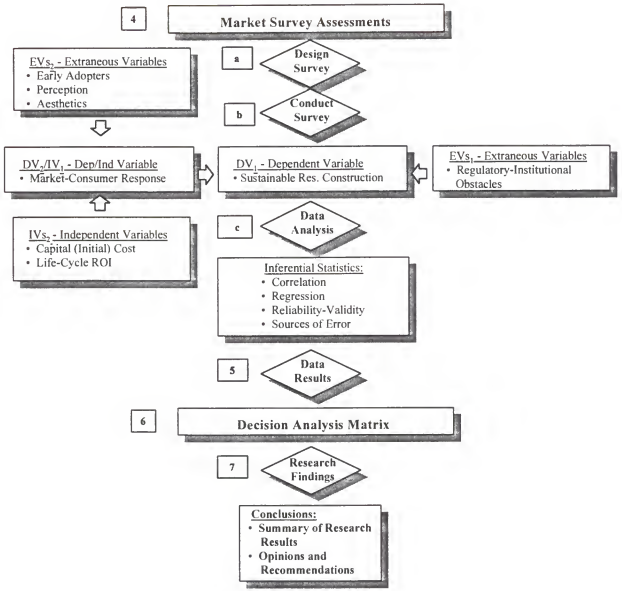

Figure 1.4. Research methodology (con't).

CHAPTER 2
RESEARCH BACKGROUND

Sustainable Development

For centuries humankind's built environment and quality of life has been closely predicated on the diversity and availability of natural resources. However, it has become evident that the ecological bounds that have provided a seemingly infinite stream of resources are showing signs of global degradation. As a result, a new focus has been placed on the concept of sustainable development. Although many definitions of sustainability exist, all essentially recognize the importance of providing for the needs of the present without compromising our ability to serve the needs of the future. The paradigm of sustainability seeks a symbiotic relationship between humankind and the environment, where human socioeconomic endeavors and the natural world engage in a mutually beneficial relationship that enhances the vitality of each.

Although the fundamental physics that govern all living things in the environment are generally well understood and accepted, the extent of human dependence on the natural system remains the basis of much philosophical debate. The purpose of using a scientific methodology in defining sustainability is to peer beyond the bounds of our limited sensory and cultural perceptions and expose the underlying and often inconceivable nature of the environment (34). At the most fundamental level, the finite capacity of the environment is unknown to most people. Consequently, the objective of this approach is to first correlate and communicate the effects of environmental degradation on the ability of a finite biosphere to provide adequate resources and waste assimilative capabilities for an exponentially growing population.

Philosophical aspects of the sustainability paradigm embody the interpretation of evidence that reveals the dependence between humans and their environment and the general state of this relationship. As a consequence, two distinct factions have formed: ecologists, who believe humankind, regardless of intellect and technology is inevitably subject to the fundamental laws of nature; and expansionists, who feel mankind is set apart and to some extent, exonerated from conforming to natural processes without adverse consequence. Table 2.1 on the following page differentiates the two competing paradigms by comparing and contrasting several ecological and economic concepts.

Table 2.1. Expansionist vs. Ecologist, competing paradigms (68).

Property or Quality	Expansionist Worldview	Ecological Worldview
Scientific origins	18th century scientific revolution, Newtonian analytic mechanics.	20th century physics, systems ecology, thermodynamics.
Central scientific premise	Nature is knowledgeable through rationalization, empiricism. Humankind external of ecosystem.	Nature is unpredictable at systems level, uncertain global change. Humankind is integral part of ecosphere.
Attitude toward people and the future	Emphasis on the immediate individual interests.	Emphasis on both present and future community needs.
Perspective of nature	Humankind is master of nature, use the environment to serve their wants and needs. Valued only as resource and waste sink.	Humankind is steward of nature, obligated to preserve. Realizes that resources ultimately control him, morale respect for life.
Economic and environmental relationship	Treats the economy separate from nature. Material and energy transformities exclusive of environment.	See the two as inseparable, dependent subsystems of ecosphere, extensions of human consumption.
Role of markets	Free markets stimulate the conservation and substitution of depleted resources through capital pricing. Lessen impact of ecosystem on growth.	Capital costs are inadequate indicators of future ecological scarcity, reveal only current exchange value and do not value life-cycle resources.
Resource substitution	Natural capital and manufactured capital are near perfect substitutes. Technology can replace any depleting resource.	Natural capital is a prerequisite for manufactured capital. Unlikely that technology will ever substitute eco- life support functions.
Role of environment in growth	Growth provides wealth distribution to developing countries to enable investment in continued future growth needed for economic prosperity.	Material growth depends on further resource depletion, increasing resource deficit, and accelerated ecological and economic decline.
Nature of limits	Practical limits on human population but not on economic growth. As technology more efficiently substitutes natural capital, dependence on resources dematerializes.	Limits on both population and growth. Total human "load" must be less than interest generated by remaining natural capital.
Carrying capacity	No limits as trade and technology can relieve any resource shortages.	Trade appears to increase capacity on local scale but invariably reduces it globally.

Other core philosophical issues confronting sustainable development are deeply rooted in the market-based concept of "equitable return." In a sustainable sense, equitable return is not an opportunistic profit, but rather a principle that the cultivation of natural capital should yield each person a livelihood and no more (12). Proponents of the expansionist (quantitative economic growth) and ecologist (qualitative economic development) philosophies differ in the fundamental interpretation of equitable return. The current expansionist system sees equitable return as the economic rent of human capital and the reward for capital risk. In an ecologically sustainable system, equitable return would include the economic rent of natural capital as well. In contrast to traditional ownership profit, there could also be a definition of profit that places life-cycle value on the natural capital the market needs for sustained economic prosperity. By definition, a sustainable society would be less interested in growth than in development, for to "grow" is to get quantitatively larger, but to "develop" is to get qualitatively better (12). Fundamental to qualitative development, sustainability must ensure that "throughputs" meet three necessary conditions:

- Use of renewable resources do not exceed rates of regeneration
- Use of non-renewable resources do not exceed rates of sustained renewable substitutes
- Generation of wastes do not exceed assimilative capacity of the environment

The sustainable development initiative emerged from the energy crises of the 1970s and the environmental decay of the 1980s. Efforts during this period seemed to define what has today evolved to become sustainability, as the boundary where the natural, social and economic systems converged or "triangulated" (proto-sustainable system). Yet to be truly reflective of the natural system from which all material and subsequently economic wealth is derived, it seems more appropriate that the economic and social system should be bound by the limits of the natural system (11). Figure 2.1 on the following page illustrates the evolution in the concept of sustainability as defined by the hierarchy of linkages between natural, social and economic systems.

The Natural System

Within the economy, "through-puts" exist as flows of material and energy from the supporting environment "through" the human social-economic system and back to the environment in degraded forms such as heat and waste. Expressed as $e = mc^2$, Einstein's Theory of Relativity states that everything ultimately exists as a form of energy (33). In a purely physical sense, all energy is sustainable in quantity but not in quality as it transforms from low to high entropy. Humankind harvests finite resources to release embodied energy that is subject to inevitable losses, which ultimately "sinks" to forms no longer useful, representing a linear, unsustainable path.

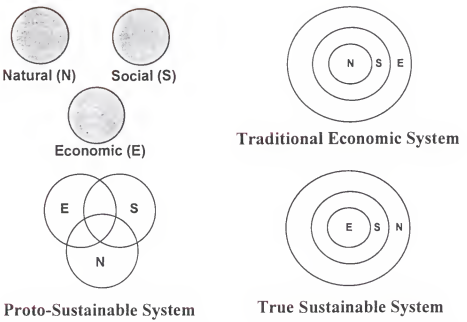

Figure 2.1. Theoretical evolution of natural, social, and economic systems interdependence.

The stored solar energy of fossil fuels is released by an oxidation process that converts complex hydrocarbons into simple molecules such as CO_2, releasing "useful" heat energy. This useful energy is but a fraction of the total energy potential that was originally embodied in the hydrocarbon as both potential and kinetic energy remain in the "spent" combustible and the thermal decomposition by-product, CO_2. If this small part of useful energy is further induced into mechanical motion or to convert heat energy to another usable form such as electricity, more energy is "lost" in the transformation process. Although the amount of energy has never changed, the work ultimately performed is but a fraction of the original energy potential. The inevitable entropic losses associated with this thermodynamic regime result in the production of between 1-2 pounds of CO_2 per kilowatt of generated power, depending on the type of fossil fuel used.

Furthermore, if a closed system cannot achieve greater or at least equal output per unit input, the system will ultimately fail. Fortunately, forms of energy exist independent of Earth's biosphere, representing a sustainable substitute to finite fossil fuels. Although "sustainable" energy resources such as geothermal, wind, hydrodynamic and solar energy are eventually subject to the same universal entropic fate as fossil fuels, in a practical sense, these forms of energy provide a renewable resource base.

Global Net Primary Production (GNPP) is the amount of solar energy captured in photosynthesis by primary producers, less the energy used in growth and reproduction. GNPP is the food resource for all organisms incapable of photosynthesis. It is calculated that 40% of the potential terrestrial and 25% of the potential GNPP is now appropriated by humans (18). Two more doublings of the world's population would consume 100% of the GNPP, leaving nothing for non-domesticated ecosystems which humans need for survival. Thus, 20+ billion humans, expected by 2100, is ecologically impossible. Present levels of per capita resource consumption underlying the economies of the West cannot be sustained without destroying the ecological sources and sinks all economic activity depends on. For example:

Let R = world resource consumption,
U.S. = 1/3 world resource consumption, or U.S. = R/3
U.S. per capita consumption = 240 million people, or R/3/240 million
Let M = number of "earths" needed to support 6 billion people at U.S. rate of consumption.
M = 6 billion/240 million/3 = 8.3

Global resource production would need to increase more than eight times to meet the resource demand of a 1997 global population living at the standards of the industrialized U.S. This figure does not account for current exponential population growth or the law of diminishing returns as output is expanded beyond the optimum, resulting in more and more material and energy resources consumed to produce fewer and fewer end products. Current rates of consumption would require 5.3 hectares per person to sustain one person (60). At this rate, Florida for example, would be able to support little more than 2.8 million people, approximately 20% of its current population.

The Social System

For the most part, living sustainably requires no deliberate acts of solidarity among member species as nature provides checks and balances that hold entire ecosystems in equilibrium. For humans however, achieving a sustainable state may require the same deliberate acts to safeguard the environment as is currently being used to exploit it. Sustainable development is widely viewed as the art, science, and technology of applying the sustainable principles of the natural system to the built environment. In terms of the social system, it simply means living within the carrying capacity of the support environment, regardless of the individual or cultural consequences. Sustainability can be considered a symbiotic exchange between the natural and social system where (1) human life can continue indefinitely; (2) human cultures can develop, and (3) the effects of human activities remain within the bounds of the ecological support system (12).

Linking the impacts of human economic activity on the natural system and the response of the social system to them, the indicators below indicate humankind is not living sustainably.

- Dwindling stocks of energy and material resources;
- Rising accumulations of wastes and pollutants;
- Capital and energy consumed to exploit more distant, dilute resources;
- Capital and energy compensating for once free natural services;
- Capital and energy used to defend or gain access to remaining resources;
- Reduced investment in human resources to meet needs or pay debts;
- Increasing conflict over remaining resources, greater social gap between haves and have-nots (12).

For those growing numbers of people who perceive an imminent threat to the environment, the sustainable revolution has become the catalyst to reverse the destructive policies and practices that evolved during the previous epoch of the industrial revolution. As a result, virtually every nation of the world has embraced the idea of sustainable development, from the United States Congress to the United Nations.

> The Congress of the United States finds that the deterioration of the quality of the Nation's environment and of its ecological balance poses a serious threat to the strength and vitality of the people of the Nation and is in part due to poor understanding of the Nation's environment and of the need for ecological balance. (Public Law 91-516)

The Economic System

As resource consumption increases in a supply-and-demand world, the cost of resources will limit, even eliminate the use of a scarce resource. Substitution will result until the demand for the scarce resource balances the ability of the environment to renew it. As an example, global deforestation for building materials, agriculture, and urban development will inevitably accelerate the cost of wood products until cost-effective substitutions are made. If no viable substitutions are found, restricted agriculture and development will result. As a "ripple effect," the increased cost of basic food and shelter will theoretically promote sustainable forestry, recycling and population control. What this expansionist view does not account for however, is the degradation to the web of interdependent ecosystems. To practice deforestation until market forces dictate sustainable resource substitution does not assess the true externalized cost of extinction, watershed pollution, or global climatic change as a result of habitat destruction, soil erosion or the inability of a declining number of forest biomes to assimilate waste byproducts and emissions.

Instead of a "comfortable" transformation to sustainable development, the ecological worldview would assert probable ecosystem collapse and extreme human hardship if it were left solely to capital market forces to dictate sustainable practice. Competitive market economies will themselves collapse unless they can reflect environmental realities. The eco-economist believes that the economic system must begin a shift from an adversary in the environmental debate to a proponent of sound environmental practice. Internalizing externalities, or assessing the cost-benefit of a product from its cradle to grave life-cycle, is the first step in a processes that will reward firms and consumers for producing and purchasing sustainable goods that do not contribute to environmental degradation once outside the manufacturer's hands. The Harvard Business School found that nations with the most rigorous environmental standards often lead in exports of affected products, offering proof that on a macro-economic scale, environmental protection does not restrict, but rather promotes economic competitiveness (12).

Can continued economic growth be reconciled with sustainable development? Many would argue that as a result of the damage they believe is attributed to the economic system, no further growth is desirable. Most contend that unlimited growth is unsustainable for any organic system, and that for all natural systems there is a size at which efficiency is optimized. The counterpoint to this argument is that for the foreseeable future, economic growth may be necessary during sustainable market transformation. Reality suggests that attempts to secure the objectives of sustainability are futile in a world ravaged by poverty. The Earth's population is expected to double by 2025, with 90% of this increase occurring in the developing world (12). Currently, one-billion people live in poverty globally. Alleviating this problem will require economic growth using market-based solutions that reflect environmental realities.

While there is strong consensus at the conceptual level about sustainable development, there are few formal models that outline the conditions for environmentally steady and sustainable growth in a decentralized market economy (13). Current measures of overall income and output of a nation, GNP, provide a highly imperfect indication of a nation's well-being. Aggregate measures of progress such as the Human Development Index (HDI) of the UN do not account for resource inequality and poverty and thus often conceal more than they reveal. By integrating environmental concerns into the core accounting process using both physical and monetary units, the true long-term productive capacity of a nation can be derived (73). By integrating economic decisions with environmental and social impacts, development decisions can be improved, resources can be better allocated, and sustainable economic investment can be optimized (56).

Current economic systems are based on circular-flow exchange values, not on the linear entropic through-put of matter and energy. Subsequently, current supply and demand economic systems do not relate the use of the environment to the resource based economy, nor does it internalize the full cost of resource consumption and waste generation, resulting in inaccurate pricing of natural resources. Benefits accrue to private interests as society pays for the externalized costs of mounting ecological debt. Although in theory market forces can attain optimal resource allocation, they cannot attain optimal scale within an economic system whose primary emphasis remains reducing capital investments, regardless of life-cycle impacts and costs. Growth beyond optimal scale or "carrying capacity" of the environment is an eventual negative for the economic system because increasingly costly resources are consumed to exploit fewer, more distant, dilute natural stocks (18). Consequently, life-cycle cost assessments and a resultant optimal scale cannot materialize in market economies without ecological criteria.

Supply and demand economies account for current resource scarcity. During the formative years of market-based economic theory, the environment was considered an infinite source of materials and an endless sink for wastes. "Free" goods such as energy, materials, water and air were appropriated with little or no exchange value. As through-puts became increasingly scarce, conventional exchange values could not account for generations of externalized pollution and resource depletion. Unlike microeconomics, macroeconomics does not account for optimal scale as no life-cycle cost-benefit structures currently exist for the economy as a whole. Without a "true-cost" function for the economic system, growth pushes beyond the optimum in the form of pervasive, detrimental externalities such as ozone depletion, destruction of old growth biomes and critical habitats, global warming, acid rain and watershed pollution.

Although quantitative growth is limited, development, or steady-state qualitative improvement independent of quantitative growth, is not. Transforming a quantitative growth dependent market economy to a qualitative development market economy occurs when sustainable principles and criteria become operationalized through life-cycle costing of resources. The result is the use of market forces to penalize resource inefficiencies and reward eco-efficiency, thereby allowing the economy to gradually become more reflective of the natural system from which all material wealth is ultimately derived. Integrating environmental criteria into the market economy is therefore considered a necessary condition for a market-based transformation process.

Environmental degradation and resource depletion transcends global economics, urban growth rates, and resource demands, leaving some form of impact, both replentishable and permanent, an unavoidable consequence of human activity. The question then is not why degradation exists, but why it takes forms and magnitudes inconsistent with many of society's environmental goals and objectives. Increasingly scarce resources are utilized in low-return, non-sustainable applications. Renewable resources, or those that can be replenished at a given rate, are being treated as extractive resources, which suggests that these resources are being *mined* rather than *managed* for sustainable yields. Other resources are placed into single uses when multiple uses would generate a larger net benefit. Resources are not being effectively recycled, and of those that are, the net embodied energy and capital investment required is often greater than those products that are conventionally produced.

Sustainable development as a "systems" response to global environmental degradation seeks a symbiotic relationship between economic prosperity and sustainable resource harvesting by linking the products of economic development to market-driven sustainable processes. Establishing sustainable criteria consistent with natural systems ecology and pricing resources according to their life-cycle efficiencies will result in an economy that rewards environmental stewardship and penalizes inefficient, destructive practices that would in time undermine both the health of the economy and the environment from which all material wealth is ultimately derived.

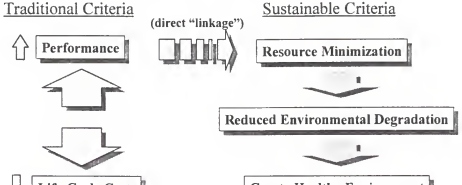

Figure 2.2. Integration of traditional and sustainable economic criteria through market-based life-cycle cost incentives promoting resource minimization.

As shown in Figure 2.2. above, residential development predicated on life-cycle costing begins to operationalize sustainability by providing market-based incentives for investment in higher performance alternatives that reduce resource use over the building life-cycle. The life-cycle ROI in fact, is due almost exclusively to the added resource efficiency of the building, where units of resources conserved are reimbursed for units of exchange value, providing further evidence of the potential integration between economic and environmental metrics.

Market-Based Eco-Economics

Development of the market-based approach to environmental regulation resulted from the inability of command-and-control structures to integrate environmental realities in the economy in-spite of punitive enforcement. Realizing that the economy is responsible for the quantitative growth that is increasingly compromising the environment's ability to sustain either itself or the economy, regulatory structures that do not provide natural links between the economy and the environment are themselves unsustainable. Figure 2.3 shows the evolution from regulatory structures to market-based approaches that begin to utilize incentives rather than punitive measures.

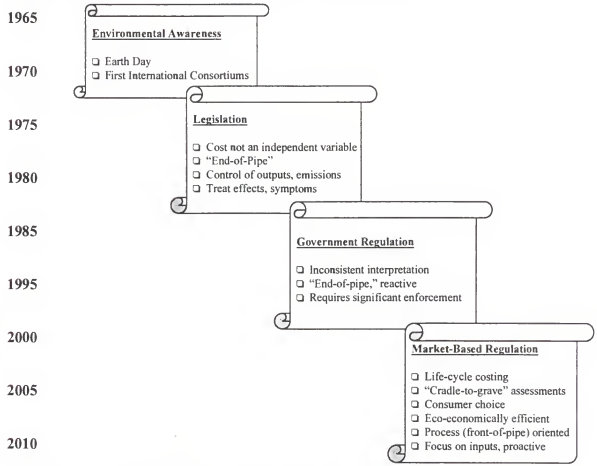

Figure 2.3. Evolution of environmental regulation from C&C to market-based incentives.

Life-cycle costing, or the valuation of a product based on its efficiencies over its cradle-to-grave life-cycle, is more reflective of natural processes, providing the first link between what is economically and environmentally efficient. As the material and energy through-puts that either compose the initial product or sustain the product throughout its useful life-cycle become increasingly valued according to ecological criteria and become more eco-economically efficient, then the economic system moves even closer to equilibrium with the natural system.

The natural system is by universal definition, the source and sink of all products and by-products derived by the economic system. The natural system, an independent variable, will ultimately dictate the size and sustainability of the dependent variable, the economy. As economic processes become more reflective of ecological processes, to the point where all economic activities can indefinitely remain within the regenerative capacity of the natural system, economic and natural systems reach equilibrium and become one in the same.

Command and Control (C&C) Regulatory Structures

As a consequence of both domestic and international pressure, environmental expenditures in the U.S. will have increased from $30 billion annually (0.9% GNP) in 1972 to $185 billion (2.8% GNP) by the year 2000. Coupled with an average 3% material cost increase, construction costs are expected to climb 4-10% to fund C&C regulation with few monetary resources left for either the market or the environment. Environmental C&C legislation has been growing at an extremely rapid rate, increasing five-fold in the 20 year period from 1972-1992. The number of pages contained in Title 40 of the U.S. Code of Federal Regulations has exploded from slightly more than 1000 in 1972 to almost 11,000 in 1990 (14). The proliferation of environmental legislation directed toward the restoration of resources and wildlife habitats has created some economic opportunities, yet has driven the capital cost of the built-environment significantly higher.

The environmental impact statement (EIS) provision of the National Environmental Policy Act requires a detailed description of possible environmental impacts "significantly affecting the quality of the human environment." Numerous states have also enacted environmental laws requiring statements that often duplicate efforts and costs of the federal EIS. The increase in design and corresponding construction costs as shown in Table 2.2. below indicates a 2.3%-7.5% and 1.6%-6.2% capital cost increase respectively to support project review and regulation (44).

Table 2.2. Costs of environmental impact statements (EIS) according to ENR 500 consultants as a percentage of total project costs (44).

Construction Type	Design	Construction
Residential and commercial	4.3%	3.4%
Highways, light infrastructure	7.3%	5.2%
Public works, heavy infrastructure	7.5%	6.2%
Industrial	6.0%	4.4%
Miscellaneous	2.3%	1.6%
Average	5.5%	4.2%

A survey of builders in Orange County, California, found the median selling price of residential development increased 1.9 times faster than the median family income due to C&C regulation in two areas: (1) fees and assessments, and (2) delays. Delays attributed to environmental legislation added approximately 3% to project costs annually in residential construction (neglecting 8%-14% inflation and 3%-9% overhead) (35). The effects of environmental regulatory changes occurring in the last ten years have been responsible for a nominal 20%-30% increase in residential construction costs in the Southwest, compared to a 90%-100% project cost increase in the Northeast during the same period (22). A comparison of regional cost variations that can result as a function of differences in environmental requirements is shown in Table 2.3 for five major U.S. housing markets.

Table 2.3. Residential cost variance among several U.S. regions due to inconsistent interpretation of environmental regulation (35).

City	Permits	Approvals	Other Costs	Total
San Francisco	$12,484.00	$1,000.00	$10,000.00	$23,484.00
Chicago	$ 4,000.00	$4,500.00	$ 6,000.00	$14,500.00
Boston	$ 3,990.00	$7,000.00	$ 1,750.00	$12,740.00
Las Vegas	$ 3,700.00	$3,458.00	$ 3,906.00	$11,064.00
Pittsburgh	$ 448.00	$1,500.00	$ 2,100.00	$ 4,048.00
Average	$ 4,924.40	$3,491.60	$ 4,751.20	$13,167.20

Air Pollution C&C Regulation. The greatest environmental impact effecting residential capital and life-cycle cost-benefit involves clean air C&C regulation. The Clean Air Act Amendments of 1990 give federal and state authorities unprecedented flexibility that will leave no sector of the nation's economy unaffected. The objective of the Amendments will be to set emission standards for 189 specific substances, namely CFCs, VOCs, and PCBs, which contribute 2.4 billion pounds of toxins into the atmosphere each year. CFCs are extremely stable molecular compounds that can remain intact in excess of 125 years. For this reason, CFCs are widely used in construction products, comprising 75% of all CFCs manufactured nationwide (45% refrigerant/coolant, 30% foam and thermal products).

Hazardous Materials Mitigation and Waste Management C&C Regulation. Subtitle C (Sections 3001-3020) of the Resource Conservation and Recovery Act (RCRA) establishes minimum federal "cradle-to-grave" legislation for hazardous waste management. Although the thrust of RCRA involves waste treatment, disposal and storage facilities (TDSFs), new attention is being given to the wastes unique to the construction industry. Compliance costs are difficult to justify during construction because personnel are unaware of the number and complexity of applicable regulations and smaller contractors cannot afford adequate training. Yet the risk of noncompliance will increasingly result in fines and delays in addition to unfavorable reputations and media coverage.

Table 2.4. 1995 construction spending for hazardous waste management ($M, 1991) (78).

Service	1991	1995
Analytical	725	980
Environmental consulting	1,230	1,700
Design and engineering	1,755	2,560
Remediation and construction	4,125	7,760
Transportation	1,172	1,184
Off-site	3,212	2,814
Total	12,219	16,998

The EPA is continuing to build an "infrastructure of trained asbestos professionals" to assess the Asbestos Hazard Emergency Response Act (AHERA) which implemented fiber mitigation throughout the nation. The EPA is expected to recommend further congressional action to extend AHERA training and accreditation requirements to work in all commercial and public buildings (4). As Table 2.4 above shows, total spending on U.S. hazardous waste management has risen approximately 29% from 1991 to 1995, a trend that is expected to increase well beyond 2000 (78).

Quantifying the net effect of environmental regulation on construction in the U.S. is heavily dependent upon evaluating the environmental effects on its resource supply and the environmental stimulus/impact on its consumer demand. Supply side manufacturing spent a record 1.6%-3.0% of their 1992 revenues for 1993 environmental compliance (51). One prominent resource supply, lumber and other wood products, has increased in price nearly 90% during the early 1990s as a result of C&C regulation affecting lumber sites controlled by the federal government, especially those involving the sustainability of a protected habitat or species, such as the northwestern spotted owl (71). The federal government owns about half the softwood supply and has placed onerous restrictions on its use, reducing production 18.2 billion board feet or approximately 24% below the 1987 peak (83). The net result is an increase of nearly $2.25/sf in most residential projects (83).

During the initial phases of land acquisition and property development, environmental regulations such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Section 404 of the Clean Water Act play dominant roles in determining the net environmental impact on capital and life-cycle development cost-benefit of the project. The effects of environmental law on the development construction phase is considered insignificant in relation to pre-construction environmental permitting costs, adding an average of 2-3 years to the project planning and development period for large developments (8, 86).

Increasing environmental awareness has also contributed to the added consumer liability for unforeseen site hazards such as subsurface contaminates or pollutants. Although it is common practice for environmental assessments to be conducted prior to property acquisition, the scope of these assessments often falls well short of the relevant environmental concerns. Furthermore, a growing number of buyers, lenders, and insurers are faced with extended liability attributed to the environmentally conscious utilization of the site throughout its useful life-cycle. Hazardous waste mitigation concerns, from landfill costs to purchasing "green" products, have become major issues, according to a survey conducted by DOW U.S.A. Thirty-two percent of the respondents claim they spend approximately $500 per newly constructed residence on disposal costs compared to nearly 10% who indicate waste removal may account $1 for every $100 of total project costs. Nearly 70% of the industry surveyed favored buying environmentally sensitive products if such products were available. Using partially recycled, or recyclable products is beginning to provide a profitable twist to the concept of waste disposal (69,70).

Market-Based Regulatory Structures

Market economies alone cannot "evolve" into a sustainable equilibrium. This assumption is based on the fundamental aspects of free market economies which seek to optimize the short-term monetary profits of the investor as well as minimize risk and uncertainty. Although it is necessary for market forces to promote sustainable development if both social and economic systems are to co-exist within the limits of the natural system, they must first begin to reflect the life-cycle cost-benefit of humankind's borrowed use of natural resources. Current market economies maximize profits for individual investors, often at the expense of social and environmental equity by exploiting devalued natural commodities. Costs for "free" resources and waste are *temporarily* subsidized by the natural system, the debt of which is ultimately paid for many times over, usually by descending classes of the social system.

As part of a social phenomenon, market economies have traditionally de-emphasized the value of cost-benefit analysis by trivializing and discounting the net present value (NPV) of life-cycle resource efficiency. As a result, devaluation of life-cycle efficiency has led to exacerbated resource scarcity and corresponding environmental degradation. Realizing that the natural system is extricably bound by the conservation principles, providing tools necessary to stimulate market interest through the economic benefits of life-cycle resource efficiency is considered a logical first step toward promoting an economy that is more reflective of the environment from which all economic activity is ultimately derived. Specifically, the market response to sustainable residential construction is hypothesized to be affected by both quantitative variables such as capital and life-cycle costs, and qualitative variables such as early adaptation, perception, and aesthetics (Figure 1.2., p. 5). The use of LCA as means to operationalize sustainable residential development within market-based regulatory structures is justified by the ability of life-cycle costing to provide "payback" data necessary to stimulate market interest in sustainable alternatives.

Market-Based Optimal Growth Paths. It is assumed that social welfare at any point is measured by a strictly concave utility function. The initial level of environmental quality and the rate of time preference are significant factors in determining the optimal choice between sustainable and unsustainable growth (5). The natural system is incorporated in endogenous growth in a way that is consistent with some simple notions from the laws of thermodynamics, which simply states that there are points at which efficiency is optimized and the limits to growth are maximized. Optimal growth in a sustainable economy must subsequently conform to three basic constraints:

- harvesting of renewable resources within natural and managed rates of regeneration.
- extracting exhaustible resources at a rate at which renewables can be substituted.
- emitting wastes within the assimilative capacity of the environment.

Market-based environmental policy and socioeconomics affects growth by influencing the consumer's perception of life-cycle investment productivity. The environment provides necessary inputs to economic production and accumulation processes. As such, improvements in environmental quality that follow market-based eco-economic policy may boost the productivity of the environment, allowing interim quantitative growth until qualitative development patterns fully emerge (74). As an alternative to non-renewable resources, industrial affluence from resource substitution may not necessarily cause environmental decay. In fact, resource substitution is necessary if pricing the environment through market forces is to render sustainable development by offering cost effective alternatives to depleted base resources.

Sustainable Construction

A subset of Sustainable Development called Sustainable Construction defines the general goals and principles that the construction industry should follow to operate with a high level of environmental awareness and sensitivity. As the construction industry senses the need to be more responsible and minimize negative environmental impacts, projects such as the Recycled House in Denmark, ReCraft 90 in Montana, Florida House in Sarasota, Florida, and the Green Builder Program in Austin, mark the *beginning* of a new era placing sustainability into the forefront of the built environment (47).

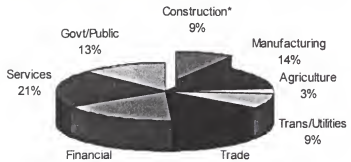

Figure 2.4. Sector distribution of U.S. GDP (7).

The 1994 Gross Domestic Product (GDP) for the construction industry was $269.2 billion, or roughly 50% of the more than $500 billion of construction placed during this year (7). The GDP of the construction industry alone was 4.4%, yet factoring all of the support services and industries directly involved in the resource extraction, manufacturing, trade, transportation, and financing of the industry, construction in the U.S. adds approximately 9% to the U.S. GDP each year (Figure 2.4). Yet from an environmentally sustainable point of view, few industries are more resource intensive even though their contributions to GDP are somewhat greater. As a result, the future availability and sustainability of a natural resource base is as much an economic concern for the industry and the U.S. GDP as it is an environmental debate.

The focus of sustainable buildings and construction is justified in light of the level of consumed resources and the subsequent generation of wastes and pollutants associated with this sector of human development. The production and use of energy causes more environmental damage than any other single economic activity. The consumption of energy results in both the overuse and depletion of finite resources, and the destruction of even more natural resources as a result of air emission pollutants. The 1994 energy efficiency index provided by the Department of Energy (DoE) indicates that the built environment consumes 36% of all energy resources and, at best, only 25% of this energy is applied to useful work (Figure 2.5) (63). As of 1995, nearly 90% of all energy production originated from fossil fuels, accounting for 75-100% of all CO_2, VOCs, CO, SO_2, and NO emissions from the transportation, building, and industrial sectors.

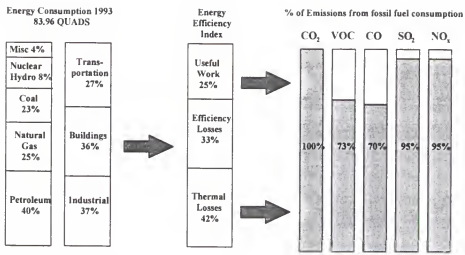

Figure 2.5. Energy consumption per sector and emissions vs "useful work" in QUADS (63).

The construction industry is defined as all parties that design, build, alter, or maintain the built environment over its life cycle; including developers, planners, architects, engineers, builders, and operators. Although other resources such as human creativity, technology and information exist; energy and watergy remain the fundamental prerequisites necessary to create and sustain the built environment. The following principles embody the goals of reducing resource depletion, minimizing environmental degradation and creating a healthy environment.

1. Minimize resource consumption (Conserve)
2. Maximize resource reuse (Reuse)
3. Use renewable or recyclable resources (Renew/Recycle)
4. Protect the natural environment (Protect Nature)
5. Create a healthy, non-toxic environment (Non-Toxics)
6. Apply life cycle cost analysis and true costs (Economics)
7. Pursue quality in creating the built environment (Quality) (47)

Principle 1: Conserve. Leads to the employment of active and passive measures to provide high performance thermal and structural envelopes, high efficiency systems, low flow fixtures, and alternative water resources, resulting in life-cycle energy and watergy resource minimization.

Principle 2: Reuse. In addition to reducing resource consumption to the minimum, it is highly desirable to reuse resources already extracted. Reuse contrasts to recycling in that reused items are simply used intact with minimal reprocessing while recycled items are in essence reduced to raw materials and used in new products with significantly greater embodied energy. Material and system items such as windows, doors, and bricks can be reused in new construction and renovation

as owners and architects strive to recapture a sense of the past in new spaces. Other resources such as water can be reused via use of graywater systems and use of third main or reclaimed water systems. Land can be reused by creating new spaces in "gray zones," areas formerly used for commercial or industrial buildings.

Principle 3: Renew/Recycle. When resources must be used, those that are recyclable, have recycled content, or that are from renewable resources must have priority over others. This principle applies to energy in cases where renewable sources such as solar and wind power are available for use. It also applies to materials which can be supplied from certified sources that provide reasonable assurances that the suppliers are managing their resources in a renewable manner. A wide range of materials are recyclable or have potentially recycled waste content.

Principle 4: Protect Nature. Another expression of Principle 4 is to exercise environmental stewardship. The complex tapestry of earth's many ecosystems and natural resources base evolved over many thousands of centuries, and the dependence of life forms on one another and on other resources is barely understood. Creating the built environment can lead to considerable resource depletion and degraded rates of resource regeneration. Considering the past and present deleterious effects on the natural environment, Principle 4 focuses on not just sustaining, but restoring the environment wherever possible. Primarily, the impacts of material acquisition practices must be scrutinized in order to minimize environmental damage.

Principle 5: Non-Toxics. Toxic materials must be eliminated to the greatest extent possible. In an effort to elevate the quality of human living, the proliferation of toxic substances from industrial processes to biocides has invaded the environment with transcended health effects on the Earth's current and future generations. The products which form the built environment and its construction contain a wide variety of hazardous and toxic substances that increasingly threaten human health and well-being. One of the major objectives of Principle 5 is to achieve good indoor air quality by selecting materials that will not off-gas or contribute particulate loading to the environment. Relative to the exterior environment, landscape design should provide for the use of plants and vegetation that are hardy, drought tolerant, and insect resistant. Using this enviroscaping strategy will minimize and perhaps eliminate the need for pesticides, herbicides, fungicides, and fertilizers that ultimately proliferate and contaminate air and groundwater resources.

Principle 6: Economics. All human interventions, including construction, have a cost beyond that which is paid by the consumers directly involved. Air and water pollution occur in zones that are the common property of all human society. The externalized costs of unsustainable activities are heavily subsidized and discounted by human made capital and economic structures, allowing the "true costs" of resource depletion and degradation to remain *temporarily* unrepresented in the devalued sale of goods and products. By not reflecting environmental realities into the market economy, the cost of this mounting ecological debt will be redeemed on future generations. Operationalizing sustainable construction means manufacturers and builders would increasingly pay for their resource consumption and waste generation, allowing market forces to reward producers providing life-cycle resource minimization through quality and performance. Second, it would motivate all economic sectors to reduce pollution and other environmental impacts to the lowest level possible. Life-cycle analysis of sustainable material, systems, and design alternatives is essential. Buildings consume over their lifetime 5 to 10 times more operational energy than their construction-embodied energy, and the same is probably true of water and material resources. Consequently the entire consumption life of the building must be considered as the basis for decision making rather than the initial capital costs alone.

Principle 7: Quality. Although often cited and equally often ignored, the notion of quality as a component of sustainable construction is vital. It includes excellence in design of buildings and selection of materials and energy systems. Another aspect of quality is durability. Systems and materials having long life cycles are more environmentally sound than those that require added energy and watergy resources to maintain.

The outcome of stating and exploring these principles is to acknowledge just how interconnected energy and watergy systems are and how greatly their life-cycle return-on-investment is requisite to their consumer acceptance in a market economy. Issues of energy crises, water shortages, air pollution, sick building syndrome, crumbling neighborhoods and infrastructure, among others, are all tightly coupled. They are not independent events as they are usually portrayed to be. Perhaps one of the problems in recognizing how tightly these matters are interwoven is that they have been treated in isolation. To solve the problems of the built environment, these compartmentalized areas of interest must be integrated. Only then will the notion of sustainable construction evolve as an integral component of sustainable development (47).

Construction put in place in the U.S. during 1997 is expected to reach an estimated $585.0 billion. Of all general contracted construction, more than a third or $103.6 billion will be residential development (Figure 2.6). Private spending on new residential housing units including subcontractors will exceed $183.3 billion in 1997 compared to $160.4 billion for all other private nonresidential construction. During the first 5 months of this year, $219.2 billion of construction was put in place, 6 percent above the $206.7 billion for the same period in 1996.

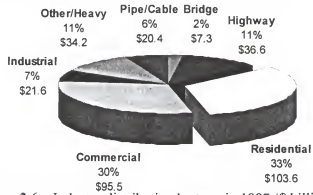

Figure 2.6 . Industry distribution by type in 1997 ($ billions) (7).

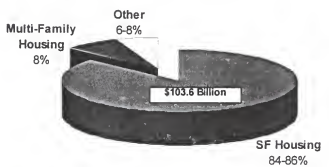

Figure 2.7. Residential distribution by type in 1997 ($ billions) (7).

Eighty-percent or more of all residential construction will be single-family detached housing (Figure 2.7). During the first 6 months of 1997, 707,300 housing units were started in the U.S. with total new housing starts for 1997 projected at more than 1,452,000. Sales of new single-family houses are expected to exceed 819,000. The national median and mean sales price of new houses sold thus far in 1997 is $142,900 and $176,400 respectively. During 1992, construction payroll in the State of Florida accounted for $30.5 billion in total dollar value of business done. Of this, $30.0 billion was for the value of construction work. Payments for construction work subcontracted to others amounted to $8.4 billion, leaving the net value of construction work at $21.6 billion (7).

Characteristics of Single Family Detached Housing

Residential construction in the U.S. has been dominated by single-family housing, amounting to more than 80% of all new residential starts from 1990-1999 (Figure 2.8). Single-family detached housing stock represents roughly 65% of the total number of residential units and floor area in Florida (58). The life-cycle resource consumption of the single-family residential sector is largely predicated on the size and number of single-family units comprising the total dwelling stock. New single-family residential housing units have increased in average floor area from 1,460ft^2 in 1966 to 1,950ft^2 in 30 years nationwide (Figure 2.9). New housing starts have increased more than 25% in the last 4 years in the south, totaling more than 600,000 in 1996 alone (Figure 2.10).

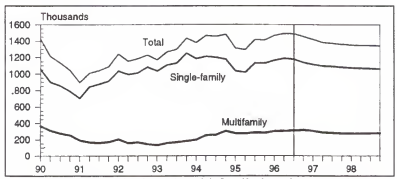

Figure 2.8. Single and multi-family housing starts by type in U.S., 1990-1998 (72).

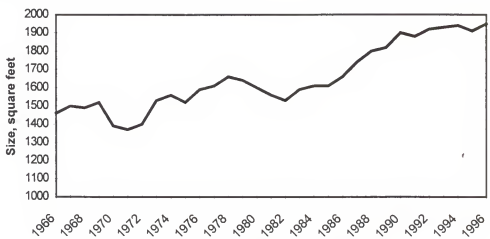

Figure 2.9. New home size trends in U.S.,1966-1996 (17).

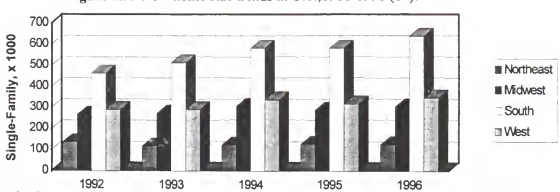

Figure 2.10. Construction of owner-occupied housing units completed by location 1992-1996 (11).

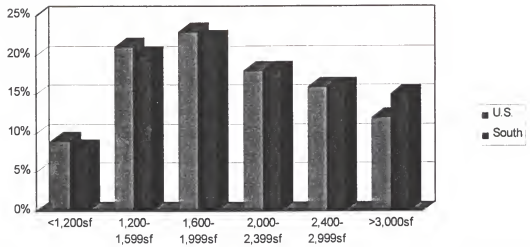

Figure 2.11. Construction of new single-family housing units by floor area 1992-1996 (11).

Residential plan type, another important criteria for determining the life-cycle resource use of the single-family housing stock in the State of Florida, is divided primarily into 1-story, 2-story and split-level design. Table 2.5 indicates a major transition in consumer preference between 1 and 2-story dwellings. Since 1985 however, the market appears to have reached equilibrium with a 40%-60% split between one and two story housing units. Figures 2.11-2.13 compare the significant size and structural differences of national and southern single-family detached dwelling stock.

Table 2.5. New home plan trends in Southern U.S., 1971-1996 (10).

Plan Type	1971	1975	1980	1985	1990	1995	1996
1-Story	85%	78%	69%	60%	57%	57%	56%
2-Story	11%	16%	27%	37%	41%	41%	42%
Split-Level	5%	6%	4%	3%	2%	2%	2%

Figure 2.12. Number of SF bedrooms, 1996 (11).

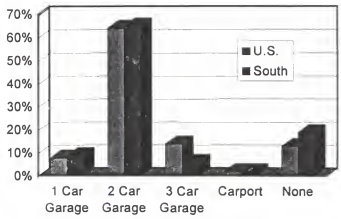

Figure 2.13. Type of parking, 1996 (11).

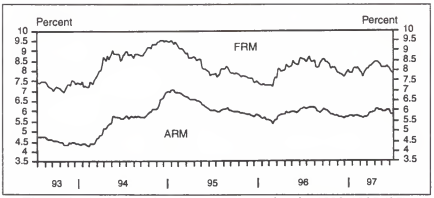

Figure 2.14. Conventional mortgage rate levels, 1993-1997 (37).

Closely related to the pricing of new, single-family detached housing as shown in Figures 2.15 and 2.16, are interest rates. As illustrated in Figure 2.14. above, interest rates have fluctuated between 7.0%-9.5% between 1993 and the end of quarter 2, 1997. The average interest rate during this period was approximately 7.5% for new home purchases, assuming a >5% principle payment.

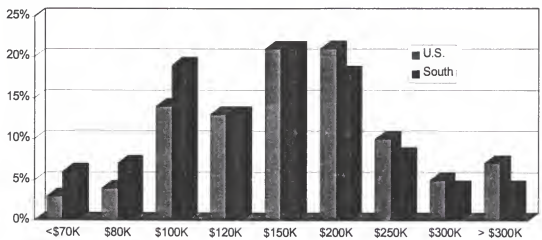

Figure 2.15. Comparison of new housing sales price, U.S. and South, 1996 (11).

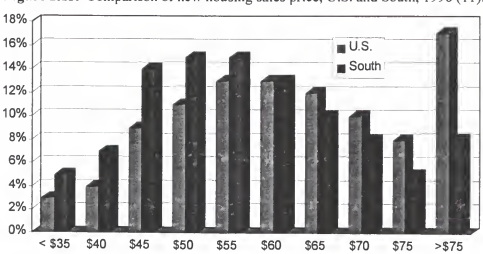

Figure 2.16. Comparison of new housing price per ft^2, U.S. and South, 1996 (11).

Characteristics of Energy and Watergy Consumption

Energy Resource Consumption and Emissions to Air. Among the most critical technologies for sustainable residential development are energy technologies. If Florida's growth continues as it has over the last forty years, the energy generating capacity of the State will be exceeded early in the coming century. Reduced energy requirements equate to less resource withdrawal and energy related pollutants. For this reason, sustainable development will be impossible without a new focus on energy use and consumption.

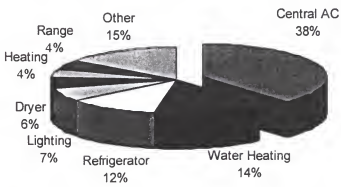

Figure 2.17. Distribution of residential energy use (55).

Residential buildings account for roughly half of Florida's electrical energy use and are responsible for approximately $5 billion in annual energy expenditures. FPL's South Florida Region accounts for one-third of the State's residential energy consumption or 2.6×10^{10}kWh in sales, 48% of which is single-family residential. Less urbanized areas such as Alachua county may have greater than 50% of its residents living in single-family detached residential dwellings. The average single family household uses about 15,000kWh annually. An estimated 30-40% of electrical energy is used for air conditioning (Figure 2.17). In contrast to national averages in Table 2.6. below, electricity remains the principal fuel for water and space heating in Florida (Table 2.7).

Table 2.6. Type of residential fuel source per application in U.S., 1993 (58).

Application	Electricity	Natural Gas	Fuel Oil	Solar	Other
Heating	29,176,000 (27.8%)	55,653,000 (53.0%)	13,511,000 (12.9%)	30,000 (n/a)	6,597,000 (6.3%)
Cooling	43,161,000 (93.3%)	2,920,000 (6.3%)	n/a	n/a	196,000 (0.4%)
Cooking	62,225,000 (59.4%)	41,781,000 (39.9%)	423,000 (0.4%)	n/a	273,000 (0.3%)
Water Heating	40,801,000 (38.6%)	57,590,000 (54.3%)	6,504,000 (6.2%)	281,000 (0.3%)	650,000 (0.6%)
Clothes Dryer	54,160,000 (76.7%)	16,281,000 (23.1%)	n/a	n/a	131,000 (0.2%)

Table 2.7. Distribution of house heating fuel in Florida, 1990 (29).

Fuel	
Utility Gas	384,495 (7.6%)
Bottled, Tank or LP Gas	371,704 (7.3%)
Electricity	4,045,573 (80.0%)
Fuel Oil or Kerosene	210,500 (4.2%)
Coal or Coke	237 (<0.1%)
Wood	39,491 (0.8%)
Solar	3,504 (0.1%)

Figures 2.18 and 2.19 provide distributions of single-family detached heating type and availability of installed cooling by region in the U.S. The vast majority of mechanical heating and cooling in Florida is provided by either vapor compression "straight" air-conditioning and gas furnace, or electric heat pumps with makeup strip heat.

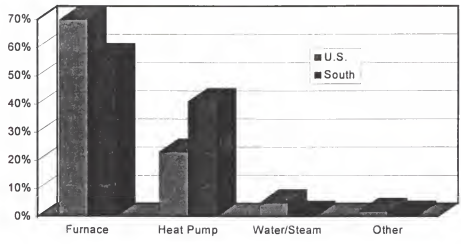

Figure 2.18. Type of heating system by housing location, 1996 (11).

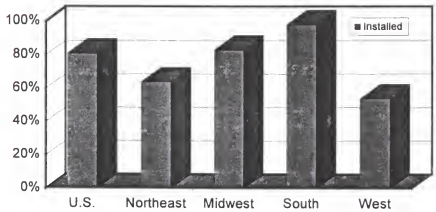

Figure 2.19. Central air-conditioning by housing location, 1996 (11).

The primary energy performance variable to consider in Florida is the cooling load. More specifically, solar loading contributes roughly 45%-50% of the heat that accumulates in the home, with solar energy falling on the roof and windows accounting for 60% of the total (Figure 2.20). The graphics in Figure 2.21 below demonstrate the change in cooling loads with respect to seasonal changes and building orientation for the northern and southern most high-growth residential areas in Florida.

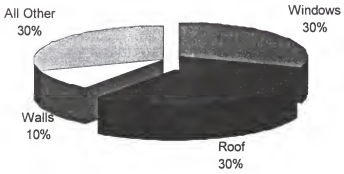

Figure 2.20. Distribution of solar loads (30).

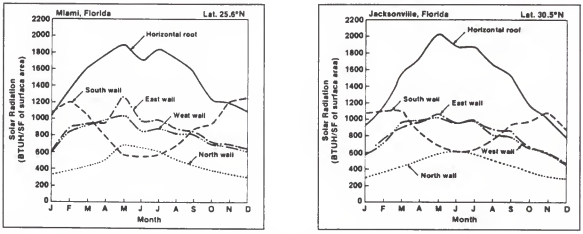

Figure 2.21. Seasonal variation in cooling loads per region (30).

Watergy Resource Consumption and Aquifer Draw-down. As the common denominator in virtually every ecosystem, water resources serve as the cornerstone of human sustainment. The finite amount of water on earth undergoes continuous reuse and regeneration while traveling through the various stages of the hydrologic continuum. Yet the demand for water increasingly approaches the limits of this slow moving cycle, compromising man's quality of life and very existence. As a consequence, sustainable water resources, conservation, recycling, and other reuse technologies will play an increasing role in water resource minimization. Such advancements in water reuse and conservation technology can now provide cost effective life-cycle ROI.

Florida's population nearly doubled from 1960 to 1980, escalated 33% from 1980 to 1990, and is expected to increase an additional 19% from 1990 to 2000 (76). Seven densely populated regions represent 60% of the State's total population and nearly 70% of its domestic withdrawal (40). With exponential population growth, agriculture and other low wage, resource intensive industries, the State of Florida is burdened by many of the same resource depletion and degradation issues that plague both industrialized and developing nations alike.

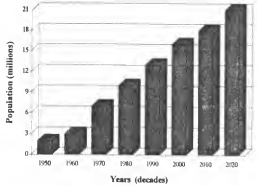

Figure 2.22. Current and projected population increase in Florida (76).

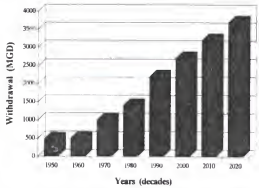

Figure 2.23. Current and projected water demand in Florida (76).

In spite of an average rainfall of 54 inches per year and limited efforts to optimize scarce water resources, withdrawal rates in Florida continue to increase proportionally with population growth (Figures 2.22 and 2.23). Use of potable water in Florida has increased by a factor of 6 in the last ninety years, with 75% of the increase occurring in the last twenty-five years. Furthermore, 80% of Florida's 14.5 million people reside near the coast. These urban developments are primarily served by shallow aquifers vulnerable to saltwater intrusion, resource overdraft, and wastewater contamination.

Potable water is defined as all water consumed for drinking, cooking, and personal hygiene. Potable water generally originates from the highest purity source and is the most rigorously treated. Calculated using a "baseline" one-hundred gal/person average consumption rate, a typical single-family detached dwelling can expect to use between 300-500 gallons per day (gpd). Residential structures use in excess of 40-60% of their potable flow for non-potable consumption, resulting in a costly, inefficient use of a limited resource (Figure 2.24). Non-potable reuse for toilet flushing alone can eliminate up to 34% of the potable residential demand.

Figure 2.24. Potable water average annual flow in SF residential structures (57).

Residential reuse coupled with water saving fixtures may be more easily accepted by the public. Efficiency of water use however, has not previously been the hallmark of fixture design. The ratio of water to waste in a conventional flush toilet is 80 to 1. It has been estimated that with the use of low cost, low water use fixtures, the amount of water used in typical residential applications can be reduced by 19 to 44 percent. Flow rates of up to 4.5 gallons per minute are characteristic of conventionally engineered showerheads whereas low-flow showerheads use 1.5 to 2.5 gallons per minute and do not lower consumer preference in terms of acceptable performance. Low-flow showerheads are either aerated or non-aerated. Non-aerated showerheads pulse the water while aerated showerheads mix air with water while simultaneously maintaining pressure. It has been reported that a 16.4 % decrease in water use occurred in a pilot program with the use of low-flow shower heads in a residential development in Amherst, Massachusetts. Low-flow faucet aerators can reduce the water flow of the average kitchen or bathroom faucet's conventional rate of 3 gallons per minute by 50 % or more (57). Figure 2.25 shows the average number of bathrooms and associated watergy fixtures in the average single-family dwelling unit located in the U.S. and in the south.

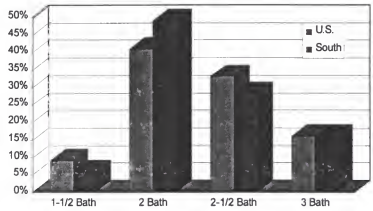

Figure 2.25. Number of bathrooms by location, 1996 (11).

Reducing the amount of water consumed by domestic systems, especially those that use heated water, may result in considerable energy savings. Domestic hot water (DHW) typically represents the second largest energy use fixture in residential buildings behind only HVAC. Table 2.8 shows the combined energy and water resource consumption of major "watergy" fixtures in residential construction. Plumbing fixtures are typically grouped into three categories including 1) pre- 1980, 2) 1980-1994, and 3) post-1994 (Figure 2.26 below). Highly efficient post-1994 fixtures mandated by the Energy Policy Act of 1992 yield approximately 62% less consumption than pre-1980 fixtures and 39% less than 1980-1994 fixtures. Since water use affects energy consumption, it is estimated that residential water use with pre-1980 domestic fixtures used 57kWh per capita, per year. By comparison, post-1994 fixtures use less than 22kWh per capita, per year; a savings of more than 60%. In 1990, over $15 billion was spent in the U.S. to heat residential water alone (20). In addition to direct watergy savings, which is defined as the savings to the end user in the form of reduced energy and water costs, watergy conservation provides costs savings to the supplier which may also be indirectly transferred back to the consumer. Indirect savings are incurred by reduced volume water treatment and supply, wastewater collection and treatment, and process energy. The average energy usage for water treatment and distribution alone ranges from 1.5-2.5kWh per kgal produced (20). Wastewater treatment may add another 1.0-1.5kWh per kgal of secondary effluent discharged. Tables 2.9-2.11 compare U.S. trends in plumbing facilities, sewage infrastructure and potable water source to those in Florida.

Table 2.8. Direct watergy savings to consumer (20).

Fixture	Electric kWh/hh/yr	Water (gal/hh/yr)
Showerhead	420-860	4,400-8,000
Faucet	31-41	1,000-1,100
Toilet	0	8,000-21,000
Dishwasher	900-935	4,500-4,750

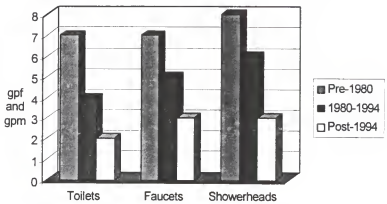

Figure 2.26. Emergence of low-flow fixture technology (20).

Table 2.9. Trends in plumbing facilities for U.S. and Florida, 1940-1990 (41).

	Complete plumbing facilities	Lacking complete facilities			Complete plumbing facilities	Lacking complete facilities	
		Number	Percent			Number	Percent
1990				**1980**			
US	101,161,982	1,101,696	1.1%	US	84,359,133	2,333,690	2.7%
FL	6,072,305	27,957	0.5%	FL	4,217,726	52,665	1.2%
1970				**1960**			
US	62,984,221	4,672,345	6.9%	US	48,537,001	9,777,783	16.8%
FL	2,361,445	127,523	5.1%	FL	1,510,304	266,641	15.0%
1950				**1940**			
US	28,729,475	15,772,717	35.5%	US	19,174,344	15,852,098	45.3%
FL	561,104	359,313	39.0%	FL	299,622	257,204	46.2%

Table 2.10. Trends in sewage infrastructure for U.S. and Florida, 1940-1990 (41).

	Public sewer		Septic tank or cesspool		Other means	
	Number	Percent	Number	Percent	Number	Percent
1990						
US	76,455,211	74.8%	24,670,877	24.1%	1,137,590	1.1%
FL	4,499,793	73.8%	1,559,113	25.6%	41,356	0.7%
1980						
US	64,240,532	74.0%	20,926,961	24.1%	1,591,224	1.8%
FL	3,076,260	71.9%	1,167,676	27.3%	34,698	0.8%
1970						
US	48,187,675	71.2%	16,601,792	24.5%	2,904,375	4.3%
FL	1,509,682	60.6%	938,352	37.7%	42,743	1.7%

Table 2.11. Trends in potable water source for U.S. and Florida, 1940-1990 (41).

	Public system or private company		Individual well	
	Number	Percent	Number	Percent
1990				
US	86,068,766	84.2%	15,131,691	14.8%
FL	5,298,184	86.9%	794,558	13.0%
1980				
US	72,528,131	83.6%	13,101,922	15.1%
FL	3,698,274	86.4%	573,059	13.4%
1970				
US	55,293,575	81.7%	11,102,324	16.4%
FL	2,085,329	83.7%	394,965	15.9%

Characteristics of Owner-Occupants

As the primary focus of this research, the market response to life-cycle ROI for sustainable energy and watergy alternatives is assumed to be predicated on the consumer willingness to pay, which is in turn predicated on the affordability of the sustainable product. To establish boundary conditions for what are in some cases likely to be higher initial cost alternatives, the margins of owner-occupant affordability within the single-family housing market must be assessed.

Table 2.12. Medium income for 4-person families, U.S. and Florida 1992-1995 (41).

	1995	1994	1993	1992
U.S. Average	$49,687	$47,012	$45,161	$44,251
Florida Average	$44,626	$43,374	$40,405	$40,369

Of the total dwelling stock in the U.S., roughly 40% is owner occupied. Owner occupants are predicted to be the most amenable population to life-cycle ROI since they have an investment incentive in both the capital cost and life-cycle resource conservation payback of the housing unit. Owner occupants comprise 39.5% of all housing in the U.S., and of those, nearly 70% carry a monthly mortgage (Table 2.13). The margin of affordability for 70.8% of all financed owner-occupants is between 20%-34% of the owner-occupant income. Generalizing this national data to the State of Florida suggests that the average annual margin of affordability for new, <2500sf single-family housing may be between $8,925.20 ($743.80/month) and $15,172.80 ($1,264.40/month).

Table 2.13. Mortgage status and selected monthly owner costs, 1990 (29).

Total Housing Units	**6,100,262 (100.0%)**
Owner-Occupied	**2,414,406 (39.5%)**
Owner with Mortgage	**1,668,542 (27.4%)**
to $499	395,054 (23.6%)
$500 to $999	882,654 (52.9 %)
$1,000 to $1,499	262,807 (15.7%)
$1,500 to $1,999	72,015 (4.3%)
$2,000 or more	$56,012 (3.5%)

Table 2.14. Monthly costs as a percentage of household income, 1990 (29).

Total Housing Units	**6,100,262 (100.0%)**
Owner-Occupied	**2,414,406 (39.5%)**
Less than 20%	95,910 (5.7%)
20%-24%	299,144 (17.9%)
25%-29%	403,654 (24.2%)
30%-34%	479,000 (28.7%)
35% or more	262,807 (15.7%)

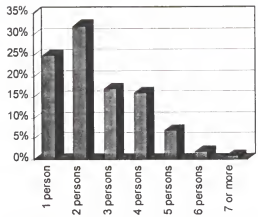

Figure 2.27. Percent distribution by size of household in Florida (41).

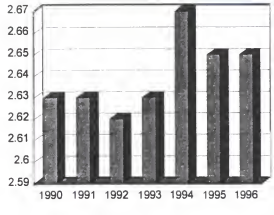

Figure 2.28. Average persons per household in Florida (41).

Another important variable to consider when assessing the life-cycle consumption of resources, especially energy and water, is the number of occupants inhabiting the housing unit. The correlation between age and number of occupants is expected to be high, as the number of inhabitants are generally greater during the "family" tenure years between householder ages 25 and 44. Also, varying correlations between age and MARR are expected, as younger, first-time owner-occupants are predicted to have less income and capability to transfer equity, thereby reducing their margin of affordability for higher initial cost sustainable alternatives. Another assumption is that younger owner-occupants are also less likely to retain their place of residence for an extended duration as the need to up-grade or relocate due to family or job pressures is greatest during householder years 25-34. Figures 2.27-2.29 show average family size and average householder age in the U.S., south and Florida. Tables 2.15-2.21 on the following pages identify the regional affordability status of owner-occupant race, age and income demographics.

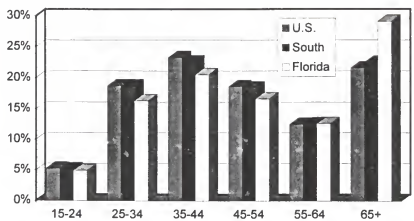

Figure 2.29. 1997 average age of householder in U.S., South, and Florida (41).

Table 2.15. Maximum-priced home that can be afforded (numbers in 000's; data may not add to total due to rounding) (41).

Maximum-priced home	Total		Married-couple		Male householder no wife present		Female householder no husband present		Unrelated individuals	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
CONVENTIONAL, FIXED-RATE , 30-YEAR										
Total	69,543	100.0	53,249	100.0	2,810	100.0	13,484	100.0	36,010	100.0
Less than $20,000	23,105	33.2	13,093	24.6	1,205	42.9	8,807	65.3	18,058	50.1
$20,000 to $29,999	1,773	2.5	1,204	2.3	123	4.4	446	3.3	1,780	4.9
$30,000 to $39,999	1,779	2.6	1,164	2.2	144	5.1	471	3.5	1,750	4.9
$40,000 to $49,999	1,620	2.3	1,194	2.2	74	2.6	352	2.6	1,463	4.1
$50,000 to $59,999	2,068	3.0	1,592	3.0	77	2.8	399	3.0	1,292	3.6
$60,000 to $69,999	2,053	3.0	1,586	3.0	114	4.1	353	2.6	1,181	3.3
$70,000 to $79,999	2,066	3.0	1,692	3.2	81	2.9	294	2.2	1,153	3.2
$80,000 to $89,999	2,361	3.4	1,960	3.7	102	3.6	299	2.2	1,155	3.2
$90,000 to $99,999	2,239	3.2	1,884	3.5	97	3.4	258	1.9	941	2.6
$100,000 to $124,999	5,006	7.2	4,323	8.1	164	5.8	520	3.9	1,836	5.1
$125,000 to $149,999	4,611	6.6	4,092	7.7	111	4.0	408	3.0	1,378	3.8
$150,000 to $199,999	7,045	10.1	6,417	12.1	233	8.3	395	2.9	1,412	3.9
$200,000 or more	13,816	19.9	13,049	24.5	284	10.1	483	3.6	2,611	7.3
Median	**$81,300**	**(X)**	**$107,300**	**(X)**	**$35,300**	**(X)**	**$20,000**	**(X)**	**$20,000**	**(X)**

Table 2.16. Affordability status for a median-priced home by current tenure (41).

Region, division, area	Total Cannot afford median priced home in area			Current owners Cannot afford median priced home in area			Current renters Cannot afford median priced home in area		
	Total	Number	Percent	Total	Number	Percent	Total	Number	Percent
CONVENTIONAL, FIXED-RATE, 30-YEAR									
United States	105,553	63,101	59.8	66,192	27,033	40.8	39,361	36,067	91.6
South	35,243	20,990	59.6	22,818	9,652	42.3	12,424	11,338	91.3
South Atlantic	18,683	11,043	59.1	12,293	5,216	42.4	6,390	5,827	91.2
East South Central	6,030	3,526	58.5	4,172	1,823	43.7	1,858	1,703	91.7
West South Central	10,530	6,422	61.0	6,354	2,613	41.1	4,176	3,809	91.2

Table 2.17. Affordability status of families and unrelated individuals for a median-priced home, by race and hispanic origin, current tenure, and type of financing: United States, 1991 (41).

Race/Hispanic origin	Total Cannot afford median priced home in area			Married-couple Cannot afford median priced home in area			Male householder no wife present Cannot afford median priced home in area			Female householder, no husband present Cannot afford median priced home in area		
	Total	Number	Percent	Total	Number	Percent	Total	Number	Percent	Total	Number	Percent
CONVENTIONAL, FIXED-RATE, 30-YEAR												
Total	69,543	35,668	51.3	53,249	22,449	42.2	2,810	1,904	67.8	13,484	11,314	83.9
White	59,038	27,755	47.0	47,892	19,243	40.2	2,277	1,474	64.7	8,868	7,039	79.4
Black	8,388	6,560	78.2	3,709	2,275	61.3	409	323	79.0	4,270	3,962	92.8
Other races	2,118	1,352	63.9	1,648	932	56.6	124	107	86.5	346	313	90.6

Table 2.18. Affordability status of families and unrelated individuals for a median-priced home, by age of householder, current tenure, and type of financing: United States, 1991 (41).

Age	Total			Married-couple			Male householder no wife present			Female householder, no husband present		
	Cannot afford median priced home in area			Cannot afford median priced home in area			Cannot afford median priced home in area			Cannot afford median priced home in area		
	Total	Number	Percent	Total	Number	Percent	Total	Number	Percent	Total	Number	Percent
CONVENTIONAL, FIXED-RATE, 30-YEAR												
Total	69,543	35,668	51.3	53,249	22,449	42.2	2,810	1,904	67.8	13,484	11,314	83.9
Under 25 years	3,693	3,563	96.5	1,739	1,629	93.7	176	173	97.8	1,777	1,761	99.1
25 to 34 years	15,666	11,839	75.6	11,128	7,519	67.6	581	484	83.3	3,957	3,836	96.9
35 to 44 years	17,748	9,085	51.2	13,594	5,686	41.8	802	591	73.8	3,353	2,808	83.8
45 to 54 years	12,067	4,809	39.9	9,679	3,192	33.0	490	283	57.7	1,898	1,334	70.3
55 to 64 years	9,403	3,011	32.0	7,891	2,088	26.5	352	174	49.5	1,160	748	64.5
65 years or older	10,967	3,360	30.6	9,219	2,335	25.3	410	199	48.6	1,338	826	61.7
Median (years)	43.7	37.7	(X)	45.2	38.7	(X)	43.1	40.0	(X)	38.0	35.2	(X)

Table 2.19. Affordability status of families and unrelated individuals for a median-priced home, by "available" money family income, current tenure, and type of financing: United States, 1991 (41).

Income	Total Cannot afford median priced home in area Total	Number	Percent	Married-couple Cannot afford median priced home in area Total	Number	Percent	Male householder no wife present Cannot afford median priced home in area Total	Number	Percent	Female householder, no husband present Cannot afford median priced home in area Total	Number	Percent
CONVENTIONAL, FIXED-RATE, 30-YEAR												
Total	69,543	35,668	51.3	53,249	22,449	42.2	2,810	1,904	67.8	13,484	11,314	83.9
No income or loss	4,163	3,934	94.5	951	805	84.7	298	269	90.4	2,914	2,859	98.1
$1 to $4,999	2,987	2,728	91.3	921	781	84.7	154	149	96.7	1,911	1,798	94.1
$5,000 to $9,999	4,856	3,865	79.6	2,397	1,744	72.7	414	333	80.3	2,044	1,789	87.5
$10,000 to $14,999	6,762	4,730	69.9	4,440	2,760	62.2	340	264	77.8	1,983	1,706	86.0
$15,000 to $19,999	7,282	4,411	60.6	5,358	2,896	54.0	321	236	73.6	1,603	1,279	79.8
$20,000 to $24,999	6,871	3,652	53.1	5,543	2,704	48.8	272	173	63.8	1,056	774	73.3
$25,000 to $29,999	5,865	3,120	53.2	4,854	2,444	50.4	231	122	53.0	780	553	70.9
$30,000 to $34,999	4,953	2,186	44.1	4,301	1,799	41.8	245	136	55.5	407	252	61.9
$35,000 to $39,999	4,611	1,853	40.2	4,158	1,615	38.8	149	96	64.8	303	142	46.9
$40,000 to $44,999	3,859	1,398	36.2	3,640	1,321	36.3	80	30	38.2	139	47	33.8
$45,000 to $49,999	3,390	1,033	30.5	3,173	971	30.6	91	22	24.3	125	39	31.2
$50,000 to $59,999	4,724	1,368	29.0	4,464	1,260	28.2	105	43	40.5	155	66	42.6
$60,000 or more	9,221	1,389	15.1	9,048	1,349	14.9	111	30	26.8	62	11	17.5
Median	$26,600	$17,900	(X)	$32,500	$24,100	(X)	$18,100	$13,800	(X)	$9,700	$7,800	(X)

Table 2.20. Regional demographics of owner-occupants in immediate metropolitan areas of Jacksonville, Orlando and Miami (29).

Population and Housing Characteristics	Duval	Orange	Seminole	Broward	Dade	Palm Beach
Total resident population:						
1995	701,673	749,631	330,012	1,412,165	2,031,336	972,093
1990	672,971	677,491	287,521	1,255,531	1,937,194	863,503
1980	571,003	470,865	179,752	1,018,257	1,625,509	576,758
Occupied housing units, 1990	257,245	254,852	107,752	528,442	692,355	659,558
Percent owner-occupied	62.0	59.3	66.9	68.0	54.3	71.9
Persons over 25 years of age, 1990	424,040	432,193	187,891	898,829	1,281,295	632,078
Percent high school graduates	76.9	78.8	84.6	76.8	65.0	78.8
Percent college graduates	18.4	21.2	26.3	18.8	18.8	22.1
Personal income, per capita	$19,820	$19,607	$20,846	$23,840	$19,266	$32,230

Table 2.21. Housing opportunity index by high-growth regional affordability rank, 1997 (48).

Region	% Homes affordable for median income	1997 Median income ($000s)	1997 Median price ($000s)	U.S. affordability rank	Southeast U.S. affordability rank
North (JAX)	76.0	43.1	91	59th	20th
Central (ORL)	76.5	43.1	95	52nd	16th
South (MIA)	59.8	39.1	100	158th	62nd

High-Growth Residential Regions of North, Central and South Florida

With 1.1 million people added to Florida's current population of 14.5 million by 2000, Florida ranks as the 4th most populous and 2nd fastest growing state in the U.S. Corresponding to a long trend of population growth, residential construction in Florida increased by a factor of 8.4 from 1940 to 1990 (Figure 2.30). The immediate metropolitan areas of Jacksonville, Orlando and Miami have represented the majority of this growth.

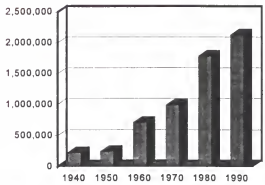

Figure 2.30. Residential construction by decade in Florida (29).

In the State of Florida, the residential dwelling stock comprises roughly 4.8 million structures and 7.3 billion square feet of inhabitable space. Single-family detached units provide the largest contribution, both in terms of number of units (3.1 million, 64.6%) and total gross area (4.7 billion ft^2, 64.4%). Figure 2.31 graphically depicts the distribution of primary housing characteristics assumed to have an impact on resource consumption associated with the residential building stock in the State of Florida. Statewide averages are compared to averages from the high-growth residential regional of north, central and south Florida as represented by the immediate metropolitan areas of Jacksonville, Orlando, and Miami. Consistent with the more urbanized nature of Jacksonville, Orlando and Miami, the percent distribution of total floor area in the combined regional population is somewhat less for single-family housing and greater for multi-family and condominium dwelling stock when compared to State averages (Figure 2.32.). The combined metropolitan dwelling stock representing north, central and south regions comprises 1.98 million units (41.3%) and 3.9 billion square feet (53.4%) of Florida's residential development.

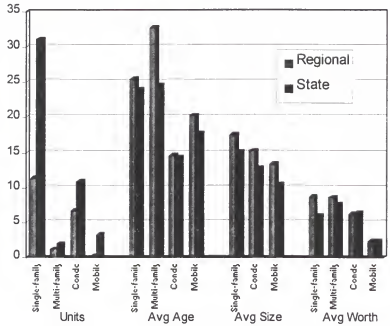

Figure 2.31. Characteristics of residential stock in high-growth Florida, 1992 (29).

Table 2.22. Residential stock in high-growth regions of north, central and south Florida, 1992 (29).

Region	Single-Family	Multi-Family	Condo-Town	Pre-fabricated
North	182,497	6,157	7,575	8,255
	(5.87%)	(3.00%)	(0.69%)	(2.59%)
Central	257,524	51,245	31,019	5,915
	(8.35%)	(24.94%)	(2.84%)	(1.86%)
South	708,103	69,810	636,532	8,565
	(22.79%)	(33.98%)	(58.25%)	(2.69%)
Total	1,148,124	127,212	675,126	22,735
	(37.01%)	(61.92%)	(61.78%)	(7.14%)

Table 2.23. Distribution of single-family dwelling stock in high-growth regions, 1992 (29).

Criteria	North	Central		South		
	Duval	Seminole	Orange	Broward	Palm Beach	Dade
Total Units	182,497	83,603	173,921	253,146	171,002	283,955
Percent of Total	5.87%	2.75%	5.60%	8.15%	5.50%	9.14%
Mean Age	31yrs	19yrs	23yrs	24yrs	23yrs	33yrs
Age Index	1.30	0.79	0.96	1.00	0.96	1.38
Average Size	1,484sf	1,969sf	1,752sf	1,820sf	1,733sf	1,772sf
Size Index	0.98	1.31	1.16	1.21	1.15	1.17
1992 Sales	6,610	4,080	7,784	14,419	8,317	14,088
Percent of Total	4.46%	2.75%	5.2%	9.72%	5.61%	9.50%
1992 Median Price	$71,100	$88,500	$82,000	$91,000	$103,500	$90,000
Price Index	1.19	1.49	1.38	1.53	1.74	1.51

A total of 3,107,237 single-family housing units were included in the State property appraiser database in 1993. The mean age for single family housing units Statewide is 23.93 years, and the average size is 1,508 sf. The number of sales in 1992 was 148,269 with a mean of median prices of $59,593. In the regional population, a total of 1,148,124 single-family housing units are included with a mean age of 25.5 years, an average size of 1,755 sf and a mean price of $87,667 (Tables 2.22 and 2.23).

Conclusions

In Florida, many of the same natural system and socioeconomic problems that have plagued the third-world continue to place a burden on the State's resource base. Overpopulation, resource scarcity, and low income agricultural industry have left many to question the sustainability of our resource dependent economy and vital ecosystems. Of the early movements toward sustainable residential development, the most promising was the fledgling community of *Civano* in Tucson, Arizona. This development demonstrated substantial consumer interest in community planning that responds to changing demographics and consumer values using a combination of environmentally responsible development and traditional village design. Village Homes, a progressive California community finished in 1982, was one of the first movements toward sustainable development. Consequently, this community is one of the only sustainable developments to have a long economic history of repeated sales and resales. Embodying most of the sustainable development criteria found in later communities, resales in *Village Homes* have averaged $11 per square foot higher than comparable homes in neighboring areas. In Florida, sustainability codes for a groundbreaking development called *Abacoa* were co-developed by UF's Center for Construction and the Environment and used several capital cost saving sustainable practices. Very few "higher" capital cost alternatives were implemented because desired consumer ROIs could not be demonstrated.

> "There are many interesting concepts (sustainable energy and watergy alternatives) presented, some that are not presently feasible, and some that could be implemented in Florida within a short period of time, given an organized educational effort aimed at the builders consumers. I would like to see a program of economically sound and acceptable Green practices developed and presented to the Florida Construction Industry." (J. Carpenter, CM, Abacoa).

This dissertation hopes to help operationalize sustainable residential construction by quantifying and qualifying the life-cycle cost-benefit of sustainable designs and systems that may one day provide a marketable alternative to capital cost oriented conventional practices. To become integrated at the local and regional level, however, it is hypothesized that sustainable development should be largely driven by market-based incentives and not solely C&C regulation. Yet to identify markets for sustainable alternatives, the capital and life-cycle cost-benefit of each must be assessed. Secondly, the consumer response (willingness-to-pay) to the life-cycle cost-benefit of sustainable alternatives must be determined. As evidenced by Abacoa, a methodology for obtaining and integrating this critical data remains largely undeveloped.

CHAPTER 3
RESEARCH METHODOLOGY

As the primary contribution, this research methodology provides the framework needed to quantify and qualify the extent to which life-cycle return-on-investment (ROI) affects consumer willingness-to-pay for sustainable energy and watergy alternatives. As a result, life-cycle cost models were developed to assess the energy and water resource minimization performance and subsequent ROI of more than fifty "greening" alternatives. The ROI characteristics for each alternative were then compared to market survey assessments, which modeled the consumer minimal attractive rates of return (MARR). As a *product* of this methodology, a sample decision analysis matrix was constructed using the data sets from the life-cycle cost models and market survey assessments to select sustainable energy and watergy alternatives that would have the greatest market advantage based on regional economic, climatic and consumer demographic criteria. The methodology for this research is provided below.

Research Questions

Primary Research Question(s)

1. To what extent will capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives?

Secondary Research Question(s)

2. To what extent will consumer cost rank with other issues (i.e., security, appearance, location) in the selection of sustainable energy and watergy alternatives?

3. What types of cost structures (i.e., total cost, interest rates, resale value, monthly mortgage) are most important to consumers?

4. To what extent do consumers assess a) margin of affordability (maximum capital cost investment), b) minimal attractive rate of return (savings-to-investment ratio, capital cost recovery period), and c) maximum return on investment in their decision to select sustainable energy and watergy alternatives?

5. To what extent will consumers understand and invest in sustainable energy and watergy alternatives that provide indirect or "soft" cost benefits (i.e., protection of the environment)?

Research Objectives

Objective I - Life-cycle Cost Modeling. Determine optimal energy and watergy alternatives based on maximum return-on-investment (ROI_{max}) categorized into 10, 15, 20 and 25 year capital cost recovery (CCR) "packages." Energy and watergy alternatives categorized in either 10, 15, 20 and 25 CCR packages were prioritized in descending order within each package by savings-to-investment ratio (SIR) to further optimize ROI.

Objective II - Market Survey Assessments. Determine the effect of life-cycle ROI on consumer response to sustainable energy and watergy alternatives. Using the optimal ROI packages identified from life-cycle cost-benefit models of *Objective I*, respondents representative of the target population were surveyed with the objective of correlating the effects of life-cycle cost-benefit on consumer willingness-to-pay for several demographic subgroups.

Objective III - Decision Analysis Matrix. Develop a decision analysis matrix using the data sets from the life-cycle cost and consumer response models to select sustainable alternatives based on regional specific economic criteria and consumer demographics. The decision matrix is designed to satisfy an industry need for a simple "score-card" that would allow home building professionals to select marketable alternatives without cost intensive value-engineering analysis.

Life-cycle Cost Modeling

The population selected for modeling the life-cycle cost characteristics of sustainable alternatives consisted of $<2{,}500 ft^2$ single family detached housing constructed since 1990 in high-growth metropolitan areas of north, central and south Florida. Cost characteristics modeled included 1) capital costs, 2) CCR, 3) SIR and 4) ROI_{max}.

Step 3a - Select Sustainable Energy and Watergy Alternatives. The method for selecting sustainable alternatives was determined by the level of conservation provided by the alternative. For the "proof of concept" purposes of this research, an alternative was selected if *any* level of energy or water resource reduction was demonstrated.

Step 3b - Select Case Study Plan-forms. Two plan-forms representing the target population were selected to model the life-cycle resource minimization and ROI of selected energy and watergy alternatives in each of the three climatic regions of north, central and south Florida. 1995 MEC compliant building components were first modeled to provide a performance "baseline."

Step 3c - Develop Sustainable Energy and Watergy Life-cycle Cost Models. The method of simulating the performance and ROI of sustainable energy and watergy alternatives began with the search and query of "greening" technologies from a resource database at the University of Florida Center for Construction and the Environment. Sustainable energy and watergy alternatives found to achieve added efficiencies over 1995 MEC compliant building components were selected. For each case-study plan-form "A" and "B," in each north (Jacksonville), central (Orlando) and south (Miami) region, 1995 MEC compliant energy and watergy alternatives were modeled to establish an average (mean) and range of energy and watergy performance "baselines." Sustainable energy and watergy alternatives were then *individually* inserted into the 1995 MEC baseline model to observe added reductions in seasonal and total annual energy and water resource consumption. Once a range and mean of energy and watergy savings was computed for each alternative modeled in both plan-forms and in each region, a straight-line ROI analysis was then conducted. Alternatives were grouped according to the time required for CCR or "break-even" point at 10, 15, 20 and 25 year intervals. Alternatives were then prioritized by SIR from highest to lowest within each CCR group, since SIR is another leading indicator of economic efficiency. Prioritization was necessary because the order that alternatives were introduced to the integrated models had a significant effect on performance and subsequent ROI.

Once sustainable energy and watergy alternatives had been placed in 10, 15, 20 and 25 year CCR packages and were ranked in descending order by SIR *within* each package, an integrated performance and payback simulation was conducted. Data were collected as each consecutive alternative was added to the simulation model to note incremental changes in total cumulative performance and payback relative to changes in performance and payback for each existing and newly added alternative. Discount rates, regional resource rates and regional capital cost adjustment factors were then added to the model. Uniform and variable discount rates were applied based on U.S. DOE projections of resource cost escalation through 2020 and variable net present values (NPVs) were computed. A detailed description of life-cycle cost modeling methods 1-6 are presented below:

1. *Independent Performance Simulation.* **a.** Determine 1995 MEC compliant building component baseline for case-study plan-forms "A" and "B" in each north (Jacksonville), central (Orlando) and south (Miami) regions. **b.** Determine the performance 1995 MEC baseline for each plan-type in each region. **c.** Individually insert each sustainable energy and watergy alternative into the baseline and observe changes in performance **d.** Establish a *range* and *mean* of performance values for each sustainable alternative from each plan-form, in each region, using unitary metrics (i.e., ΔMBtu/kHDD/100ft^2/yr, Δgpm/fixture/yr).

2. *Independent Straight-line ROI.* **a.** Determine the difference in capital costs between 1995 MEC baseline alternatives and "competing" sustainable alternatives. **b.** Provide an average unit cost for energy and water resources ($/kWh, $/1000gal.) from three regions. **c.** Determine the changes in case-study annual performance costs for each energy and watergy alternative based on observed changes in performance for each plan type and region. **d.** Set the increase in capital costs equal to the product of 1) the annual cost savings of each sustainable alternative and 2) time (n) to determine the straight-line CCR (Δ capital cost = [$\Sigma\Delta$ annual performance savings]n), solve for "n." **e.** Subtract the increase in capital costs from the product of 1) the annual cost savings of each sustainable alternative and 2) the alternative service life (n_{SL}) to determine the *maximum return on investment* (ROI_{max} = [($\Sigma\Delta$ annual performance savings)n_{SL} - Δ capital cost]. **f.** Divide the increase in capital costs by the total cost savings of each alternative to determine the *savings-to-investment ratio* (Δ capital cost/ ROI_{max}).

3. *Independent Alternatives Prioritization.* **a.** Place energy and watergy alternatives into 10, 15, 20 and 25 year CCR "packages" **b.** Prioritize alternatives within each package by SIR in descending order.

4. *Integrated Performance Simulation.* **a.** Repeat performance simulation from *method 1*, with the exception of inserting cumulative sustainable alternatives into the baseline case-study by order of prioritization from *method 3*. **b.** Observe changes in overall case-study plan-form unit performance (ΔMBtuh/kHDD/100ft^2/yr, Δgpm/fixture/yr). **c.** Establish a *range* and *mean* of performance values for each cumulative energy and watergy alternative.

5. *Integrated Straight-line ROI.* **a.** Repeat straight-line ROI simulation from *method 2* using cumulative performance simulation data from *method 4*. **b.** Compare and contrast incremental changes in 1) CCR and 2) ROI_{max} for each sustainable energy and watergy alternative **c.** Provide a cumulative case-study 1) CCR and 2) ROI_{max} for each plan-form and region.

6. *Integrated Amortization ROI.* **a.** Modify *method 5* to account for future resource discount rates and regional capital cost differences. **b.** Simulate changes in 1) NPV 2) CCR, and 3) SIR for each sustainable energy and watergy alternative for each plan-form and region.

Market Survey Assessments

The design of the market survey assessments includes a descriptive-correlational methodology necessary to determine the extent life-cycle cost-benefit affects consumer willingness-to-pay for sustainable energy and watergy alternatives. The population selected for the survey consisted of owner-occupants residing in <2,500ft^2 single family detached housing constructed since 1990 in high-growth metropolitan areas of north, central and south Florida. Respondents were surveyed with the intention of correlating changes in consumer willingness-to-pay to changes in consumer demographics.

Step 4a - Design Market Survey. The method for the design of the survey instrument was to develop a telephone questionnaire divided into several "themes," each addressing specific research questions. The instrument consisted of quantitative and qualitative questions in closed-ended and Likert format ranging from a strong positive position (very important, strongly agree, very likely) to a strong negative position (very unimportant, strongly disagree, very unlikely). The sequence of questions began with those considered least "invasive." Questions were designed to produce both categorical (nominal) and interval data for statistical analysis.

Step 4b - Conduct Market Survey. Data were collected from telephone questionnaires to respondents within the stratified sample frame of owner-occupants consisting of "head-of-household" homeowners occupying single-family detached housing units constructed since 1990 in the immediate metropolitan areas of Jacksonville, Orlando and Miami Florida. Telephone was the medium of choice because of the increase in response rate, timely completion and complexity of the subject matter. The general method for developing and conducting the survey included:

1. *Draft Survey Instrument.* Design of draft survey instrument was completed prior to obtaining approval from Doctoral Committee Chair and the members of the Doctoral Committee.

2. *IRB Approval.* Approval from University of Florida Institutional Review Board was obtained following approval from the Doctoral Committee.

3. *Random Sample List.* The total number of random responses in target population necessary to achieve +/-5% permissible error at the 95% confidence level was calculated to be $n = 384$ which was rounded to $n = 400$ for conservancy. To arrive at 400 survey completions, a total of 4,172 parcel numbers of "candidate" respondents matching the criteria of the target population were selected, of which 80% (3,337) were successfully coded with names and addresses. 1,335 respondents or 40% of the 3,337 were successfully paired with telephone numbers. 30% of the 1,335 candidates completed the survey, resulting in the desired 400 survey completions necessary to achieve +/-5% error at 95%. The number of responses collected from each county in north, central and south Florida was determined by the number of owner-occupants from each region.

4. *Pilot Test Survey.* Testing of the instrument was completed to identify corrections to the instrument necessary to enhance the validity and reliability of the survey to a Cronbach alpha level (α) of 0.10.

5. *Survey Administration.* Once revisions to the instrument had been completed, the survey was administered to the randomly selected stratified sample frame. All questionnaires were coded to identify non-respondents with confidentiality maintained. To control non-response error, responses from a random sample of non-respondents would be compared to those who responded during the survey to evaluate the representativeness of the respondents. Interviewers were given extensive training to ensure consistent administration of the instrument.

Step 4c - Evaluate IV and EV "Actors." Data collected to answer research questions and subsequently evaluate independent and extraneous variables affecting consumer response to sustainable alternatives, was analyzed using methods to describe, correlate and draw inference to statistically significant relationships. descriptive analysis involved frequency distributions and measures of central tendency. Correlational and inferential analysis included techniques to identify the covariance of two or more variables using correlation coefficient r and regression for interval level data and *chi square* (X^2) for tests of significance among categorical data.

Data Analysis

Market survey assessment results were analyzed using Microsoft EXCEL® with the intent of identifying statistically significant relationships that could provide insight toward answering research questions. Consequently, two or more survey questions were developed to directly or inferentially answer each research question. Descriptive data representing the overall MARR tendencies of the population were expressed using a variety of distribution graphics. Consumer preferences and willingness-to-pay data were then computed for each consumer demographic group to identify trends and relationships specific to one group or another that significantly deviates from the overall population.

Decision Analysis Matrix

To provide industry with a simple "score-card" that would allow building professionals to efficiently select sustainable energy and watergy alternatives based on level of market demand, the integrated amortization performance of each alternative in each region was plotted within the domains of observed willingness-to-pay profiles from major consumer demographic groups. The cost-benefit of sustainable alternatives were plotted as function of savings-to-investment ratio (SIR, x-axis) and capital cost recovery (CCR, y-axis) and divided by the willingness-to-pay domains of single demographic groups. In practice, the SIR and CCR performance of sustainable energy and watergy alternatives "falling" within the domain of a given demographic group most desiring a similar range of SIR and CCR performance would be selected for implementation if the demographic group was the targeted market. A visual basic "screen" was then developed to provide a sample of how a computerized application of the decision matrix could appear.

Research Findings and Results

A synopsis of research findings and results was presented including 1) a summary of research results, 2) opinions and recommendations, and 3) a discussion of research limitations, sources of error and uncertainty. First however, the ecological impacts of using life-cycle cost models, market survey assessments and the resultant decision analysis matrices as a market-based approach to promote the use of sustainable energy and watergy alternatives in new housing entering the dwelling stock in Florida from 2000-2020 was addressed. A hypothetical look at point source energy, embodied energy and attendant air-emissions that could be potentially reduced or eliminated as a result of the market elasticity for sustainable energy and watergy alternatives was included. Finally, a conceptual framework for energy and air-emission reductions possible as a result of incremental taxation on resource inefficiency and credits for resource efficiency were established as a topic for further research.

Conclusions

The goal of this research was to develop a methodology for operationalizing sustainable residential development by providing the methods necessary to assess the market potential of "greening" technologies in single-family housing, and in particular, the extent life-cycle ROI affects consumer willingness-to-pay for these alternatives. Although a significant factor, the life-cycle cost-benefit of energy and watergy alternatives is but one of many variables affecting the market acceptance of greening the built environment. This research will provide a foundation on which more advanced techniques capable of assessing the "true" or "soft" cost cradle-to-grave impact of resource use in other development sectors can be built. As a result, the basic theory and research from which this methodology was derived may be applied within the building industry with the understanding of its limitations and unresolved issues that as for all technologies, fuel the need for continued research.

CHAPTER 4
LIFE-CYCLE COST MODELING

Introduction

The goal of this section is to provide a *methodology* that will enable building professionals to select sustainable alternatives that would in turn, provide the consumer an "optimal" return-on-investment (ROI). Optimal ROI can be defined as any one or a combination of desired "pay-back" scenarios where the consumer invests in an alternative to conventional building practices to take advantage of reduced resource consumption and subsequent life-cycle costs. Some of the most significant regimes found to influence consumer willingness-to-pay are a) capital cost recovery (CCR), b) savings-to-investment ratio (SIR), and c) maximum return-on-investment (ROI_{max}). Since each of these life-cycle cost variables affect consumers differently, a methodology for modeling the cost characteristics of each alternative must be accomplished. Once completed, alternatives can be selected according to their marketability to specific demographic groups, resulting in "optimal" payback to the consumer, maximum market implementation and subsequent resource conservation.

Conditions, Approach and Limitations

The population selected for modeling the life-cycle cost characteristics of sustainable alternatives consists of "typical" 2,500ft^2 or less single-family detached housing constructed since 1990 in high-growth metropolitan areas of north, central and south Florida. Housing of this type is representative of nearly 65% of residential structures in Florida (some 3.1 million units and 4.7 billion ft^2 total living space) and is one of the largest contributors to both the State's GDP and resource consumption. High-growth north, central and south Florida defined as the immediate metropolitan areas of Jacksonville, Orlando and Miami represents more than 50% of Florida's owner-occupant population, and for energy modeling, the most extreme climatic variance possible.

The first step in the development of an approach to quantify the cost characteristics of sustainable energy and watergy alternatives is to define what measures or metrics are being used to differentiate sustainable alternatives from conventional building components. For the purposes of this research, sustainable alternatives were defined by whether resource use, on any scale, would exceed 1995 Model Energy Code standards.

Once the criteria used to segregate sustainable alternatives from non-sustainable or conventional alternatives has been developed, the domain of the "cradle-to-grave" life-cycle to be modeled must be established. For the purposes of this study, only energy and watergy resources were evaluated (Figure 4.1, x-axis). Material alternatives were excluded because performance "payback" is an indirect or *passive* function of durability and added service life that is not readily interchangeable into models developed to evaluate the *active* energy and watergy performance. Land or site alternatives were not included because as a boundary condition, the performance modeling is limited to only sustainable alternatives located within the building envelope.

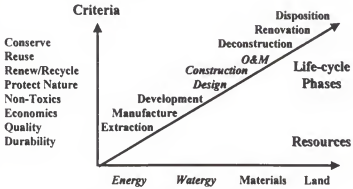

Figure 4.1. Life-cycle resource flows throughout the building life-cycle.

Sustainable material and land alternatives also have a significant "soft" cost impact, such as reduced habitat destruction and watershed pollution, that could not be adequately accounted for by models developed to assess the "hard" cost return-on-investment of energy and watergy alternatives. For the same reason, the life-cycle construction phases (Figure 4.1, z-axis) were limited to only the design, construction, and O&M phases, providing focus on the hard or direct costs borne by the consumer.

Having established 1) the criteria for selecting sustainable alternatives and 2) the domain for life-cycle cost accounting (LCA), two case-study housing units were selected to model the resource minimization performance of sustainable energy and watergy alternatives in each of the three climatic regions of north, central and south Florida. For each plan-form, further referred to as plan-forms "A" and "B," building components were selected to comply with the 1995 Model Energy Code (MEC) for single-family dwelling units (Table 4.1 and 4.2). Plan-forms A and B constructed with 1995 MEC building components would then provide a "baseline" of typical housing being placed in service since 1990. Sustainable energy and watergy alternatives would then be compared to the 1995 MEC baselines to identify enhancements in performance and subsequent return-on-investment.

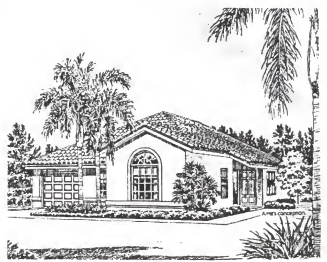

Figure 4.2. Case study plan-form elevation "A".

Figures 4.2-4.5 illustrate the plan and elevation for case studies A and B. Developed for the Abacoa project, both single and two-level home models are typical of single-family detached housing in Florida and fully conform to the boundary conditions of the stated research population.

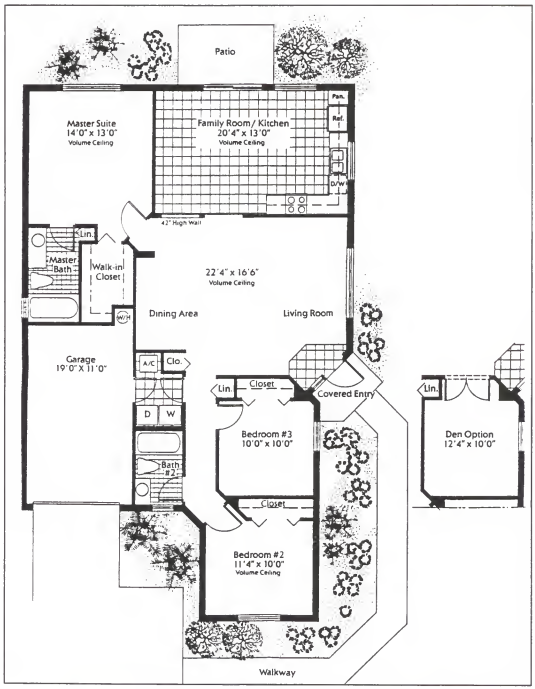

Figure 4.3. Case study plan-form "A."

Conditioned floor area: 1,440 ft^2
Roof area: 2,360 ft^2
Total glass area: 177 ft^2
Net exterior wall area adjacent to conditioned space: 1,300 ft^2

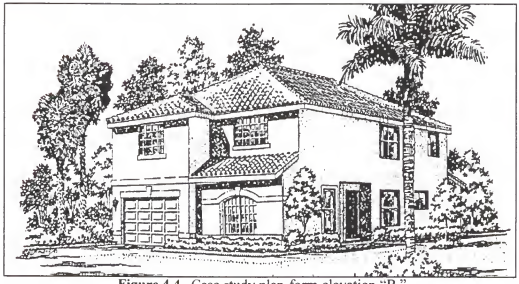

Figure 4.4. Case study plan-form elevation "B."

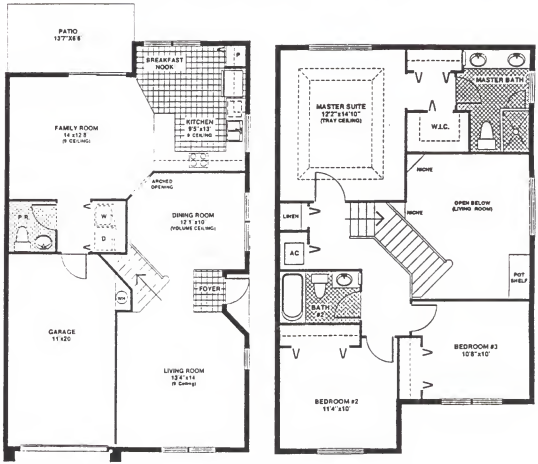

Figure 4.5. Case study plan-form "B."

Conditioned floor area: 1,700 ft^2
Roof area: 2,090 ft^2
Total glass area: 270 ft^2
Net exterior wall area adjacent to conditioned space: 2,205 ft^2

Table 4.1. Plan-form representativeness and deviation from State, regional and U.S. averages.

General Characteristics	Plan-form A	Plan-form B
Total floor area (sqft)	1,440	1,700
σ mean, Florida, 1992 (1,508sf., total stock)	(0.95)	(1.12)
σ median, South, 1996 (1,990sf., new construction)	(0.73)	(0.86)
σ median, U.S., 1996 (1,940sf., new construction)	(0.75)	(0.88)
Plan type	1-story	2-story
South, 1996	(56.0%)	(42.0%)
Bedrooms	3-bedroom	3-bedroom
South, 1996	(62.0%)	(62.0%)
U.S., 1996	(53.0%)	(53.0%)
Bathrooms	2-bath	2½-bath
South, 1996	(48.0%)	(28.0%)
U.S., 1996	(42.0%)	(33.0%)

Table 4.2. Minimum 1995 MEC compliant building components with representativeness of State, regional and U.S. single-family detached housing.

Detailed Characteristics	Plan-form A	Plan-form B
Site orientation axis	E-W	E-W
Trees, shade	none-minimal	none-minimal
Thermal envelope, walls	2 x 4 frm, R-11, siding or 8" CMU, R-5 rigid	2 x 4 frm, R-11, siding or 8" CMU, R-5 rigid
Thermal envelope, ceiling	2 x 6 jst/cord, R-19	2 x 6 jst/cord, R-19
Exterior doors	SC, wood-stl/poly R-2	SC, wood-stl/poly R-2
Windows, sliding doors	¼ single pane, alum sash	¼ single pane, alum sash
Eave, shade	Soffit, 16 in.	Soffit, 16 in.
Exterior finishes, reflectance	moderate	moderate
Infiltration, leakage	moderate	moderate
Radiant Barrier	no	no
Slab, perimeter insulation	no	no
HVAC	ASHP 7 HSPF, 10 SEER	ASHP 7 HSPF, 10 SEER
Florida, 1990 (electric heat)	(78.0%)	(78.0%)
South, 1996 (Heat pump heating)	(41.0%)	(41.0%)
South, 1996 (cooling, ASHP or Straight A.C.)	(96.0%)	(96.0%)
Duct loss	moderate	moderate
Indoor lighting	60W, incandescent	60W, incandescent
Water heater, insulated	Electric, no	Electric, no
Programmable thermostat	no	no
Dishwasher	yes	yes
Clothes washer, low-flow	yes, no	yes, no
Dryer	yes, electric	yes, electric
Refrigerator	yes	yes
Lavatory/sink fixtures	2.5 gpm	2.5 gpm
Shower fixtures	4.0 gpm	4.0 gpm
Toilet fixtures	4.0 gpf	4.0 gpf
Potable water source	municipal	municipal
Florida., 1990	(84.2%)	(73.8%)
U.S., 1990	(86.9%)	(74.8%)
Sewage	municipal	municipal
Florida, 1990	(73.8%)	(73.8%)

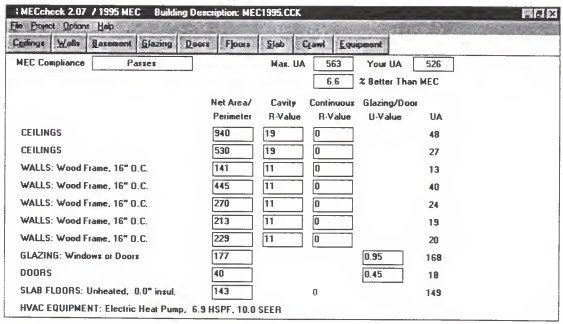
MECcheck 2.07 / 1995 MEC Building Description: MEC1995.CCK
File Project Options Help
Ceilings Walls Basement Glazing Doors Floors Slab Crawl Equipment
MEC Compliance Passes
Max. UA 563
Your UA 526
6.6 % Better Than MEC
Net Area/ Perimeter
Cavity R-Value
Continuous R-Value
Glazing/Door U-Value
UA
CEILINGS 940 19 0 48
CEILINGS 530 19 0 27
WALLS: Wood Frame, 16" O.C. 141 11 0 13
WALLS: Wood Frame, 16" O.C. 445 11 0 40
WALLS: Wood Frame, 16" O.C. 270 11 0 24
WALLS: Wood Frame, 16" O.C. 213 11 0 19
WALLS: Wood Frame, 16" O.C. 229 11 0 20
GLAZING: Windows or Doors 177 0.95 168
DOORS 40 0.45 18
SLAB FLOORS: Unheated, 0.0" insul. 143 0 149
HVAC EQUIPMENT: Electric Heat Pump, 6.9 HSPF, 10.0 SEER

Figure 4.6. 1995 MEC compliance audit for baseline plan-form "A," Jacksonville, FL.

To validate the compliance of "baseline" energy and watergy alternatives with 1995 MEC standards, the MECcheck 2.07™ software package developed by the U.S. Department of Energy was used. Based on the building components and the local climate, MECcheck 2.07™ determines the level of compliance or non-compliance with MEC 1995. Evaluating plan-form A in the Jacksonville (north) region, MECcheck 2.07™ found that the baseline meets the minimum MEC 1995 standard (Figure 4.6). To determine individual building component compliance with 1995 MEC, Table 4.3 is used. Climate zones 1, 2 and 3 represent south, central and north regions of study.

Table 4.3. 1995 MEC component compliance tables, envelope insulation.

	MAXIMUM				MINIMUM			HVAC
Package	Glazing* Area %	Glazing U-value	Ceiling R-value	Wall R-value	Floor R-value	Slab Perim R-value	Crawl Spc R-value	Equipment Efficiency
Zone 1: Miami, FL (South Region)								
1	12%	>1.0	R-13	R-11	R-11	R-0	R-0	Normal
2	15%	>1.0	R-19	R-13	R-11	R-0	R-0	Normal
3	18%	0.90	R-19	R-13	R-11	R-0	R-0	Normal
Zone 2: Orlando, FL (Central Region)								
1	12%	>1.0	R-19	R-11	R-11	R-0	R-4	Normal
2	15%	0.90	R-19	R-13	R-11	R-0	R-4	Normal
3	18%	0.75	R-19	R-11	R-11	R-0	R-5	Normal
Zone 3: Jacksonville, FL								
1	12%	>1.0	R-30	R-11	R-11	R-0	R-5	Normal
2	15%	0.90	R-30	R-13	R-11	R-0	R-5	Normal
3	18%	0.75	R-26	R-11	R-13	R-2	R-6	Normal

* Glazing as a percentage of wall area.

To model the energy performance of sustainable alternatives, the REM/*Design*™ residential energy analysis and code compliance program developed by the Architectural Energy Corporation was used. Of the 125 software packages reviewed by the U.S. Department of Energy, REM/*Design*™ was listed as a "user-friendly, yet highly sophisticated, residential energy analysis and code compliance software" tool. In addition to calculating energy performance, REM/*Design*™ automatically determines compliance with the MEC and ASHRAE 90.2 and allows side-by-side comparisons of two or more plan-forms. Although considered the most appropriate computational modeling software package available, REM/*Design*™ was limited to energy analysis, 1995 MEC compliance and simple pay-back modeling (Appendix II). To include watergy analysis as well as amortized LCA, new models were developed.

Approach. Life-cycle cost modeling began with the search and query of "green" building alternatives from a resource database at the University of Florida's Center for Construction and Environment. Energy and watergy alternatives found to achieve resource minimization were selected. For each case-study plan-form "A" and "B," in each north (Jacksonville), central (Orlando) and south (Miami) region, conventional 1995 MEC compliant energy and watergy alternatives were modeled to establish an average and range of energy and watergy performance "baselines." Sustainable energy and watergy alternatives were then *individually* inserted into both 1995 MEC compliant plan-forms, in each of three regions, producing a total of six data points for each alternative. These six data points represented the observed changes in energy and watergy performance attributed to each alternative and were divided by 1) the specific unit quantities of each plan-form, and 2) the regional heating degree days (HDDs) or cooling degree hours (CDHs). The average of the six "unitized" data points would then represent the added reduction in energy or watergy load or consumption attributed to each sustainable alternative compared to a MEC baseline.

For plan-form "A" in Miami, ¼" acrylic single-pane glazing is 1995 MEC compliant based on the overall performance of the baseline insulating and HVAC alternatives used ("whole house" as opposed to prescriptive analysis). As a sustainable alternative, double-pane, reflective glazing is modeled in place of single-pane glazing. For plan-forms A and B in north, south and central Florida, results indicate that between these six data points, a range of 0.20115 and 0.23396 MBtu/100ft²/kCDH of cooling load will be reduced, or, an average of 0.21795 million Btu per thousand cooling degree hours for every 100sf of glazing. The deviation between the six data points for this example is +/-7%. For most of the sustainable energy and watergy alternatives, deviations range from 6%-30%, meaning that the reductions in average unit loads could be factored by the unit quantities and regional HDD/CDH of a given single-family dwelling unit to estimate an overall, "order-of-magnitude" energy and watergy reduction. The non-amortized value of these reductions could then be compared to the added cost, if any, of the sustainable alternative.

Also referred to as "simple payback," the added capital cost for each sustainable alternative was subtracted from the non-amortized value of resource savings over the estimated service life of the alternative, providing an ROI_{max}. By dividing the added capital cost of an alternative by the annual value of resource savings, a CCR or "break-even" point was established. A third indicator of economic efficiency, SIR, was calculated by dividing ROI_{max} by the added capital cost of each energy and watergy alternative. Alternatives were then placed into groups or "packages" according to the time required for CCR or "break-even" point at 10, 15, 20 and 25 year intervals. Since only one alternative for each building component could be used within each CCR package, the alternative with the highest ROI_{max} was selected. Results of market survey assessments in Chapter 5 found that ROI_{max} was the most significant life-cycle cost variable affecting consumer willingness-to-pay, even though CCR and SIR are generally considered better indicators of economic efficiency. Alternatives in each 10, 15, 20 and 25 year CCR package were then prioritized by SIR from highest to lowest. Prioritization was necessary because the order that alternatives were introduced to the integrated models to follow had a significant effect on the performance and subsequent ROI of each alternative, meaning if for affordability reasons, only a *partial* package could be used, those alternatives with the highest SIR should be selected first.

Once sustainable energy and watergy alternatives had been placed in 10, 15, 20 and 25 year CCR packages and were ranked in descending order by SIR *within* each package, an integrated performance and payback simulation was conducted. Since energy alternatives in particular have a declining utility function whereby the marginal benefits of each added alternative decline as the number of total alternatives increases, the *cumulative* performance and cost savings of energy and watergy alternatives modeled independently of one another (in the previous steps) cannot be used. Instead, data were collected as each consecutive alternative was added to the simulation model to note incremental changes in total cumulative performance and payback. To provide an sample of this methodology, the *individual* and *integrated* cumulative unit average of energy and watergy reductions for each alternative were modeled using the climatic characteristics of Orlando, FL (34.0CDH, 0.7HDD).

Having arrived at an integrated performance and payback regime, discount rates, regional resource rates and regional capital cost adjustment factors were added to the model. Uniform and variable discount rates, or the variance in energy and water inflation with respect to general inflation, were applied based on U.S. DOE projections of resource cost escalation through 2020. A net present value (NPV) of total package savings and individual energy and watergy alternative savings was then computed for a sample 15 year CCR package in all three regions.

Independent Energy and Watergy Performance Simulation Summary

For each north (Jacksonville), central (Orlando) and south (Miami) region, 1995 MEC compliant energy and watergy building components for both case study plan-forms were modeled to establish performance "baselines." Sustainable energy and watergy alternatives (Appendix I, p 170) were then inserted *individually* into the baseline for each plan-form in each region to observe changes in life-cycle performance. The mean (avg) change in performance for each alternative was recorded along with the minimum (min) and maximum (max) changes in performance. These changes in performance were divided by the specific unit quantities of each plan-form and the regional HDDs or CDHs. From this, a unit metric representing the average load reduction attributed to a given unit of a sustainable energy or watergy alternative per given unit of heating or cooling degree days could be determined.

In the example provided by Figure 4.7, single-pane LoE windows were found to reduce the cooling consumption of a 36kBtu, 10 SEER air-source heat pump an average of 0.03828 MBtu/100ft^2/kCDH when used in place of the minimal 1995 MEC window alternative. This average was determined by the mean of six data points modeling the performance of single-pane LoE windows in both plan-forms A and B, simulated in north, central and south regions of Florida. The maximum unit change in performance was 0.04158 MBtu/100ft^2/kCDH, observed in plan-form "A" in Miami. The minimum unit change in performance was 0.03487 MBtu/100ft^2/kCDH, observed in plan-form "B" in Orlando. The average deviation across the range of simulation values was 8.8% (Table A-II.13). Assuming a linear increase in load and consumption reductions proportional to an increase in cooling degree hours, graphs similar to Figures 4.7-4.13 can be constructed to predict energy savings for a given unit of a sustainable energy or watergy alternative. As shown below, the unit annual energy savings of different window alternatives can be estimated for each north, central and south region.

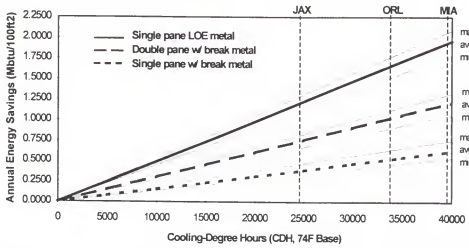

Figure 4.7. Energy efficient window alternatives (single pane, metal sash baseline). JAX = Jacksonville, ORL = Orlando, MIA = Miami.

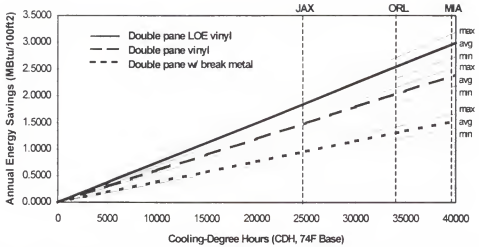

Figure 4.8. High-energy efficiency window alternatives (single pane, metal sash baseline).

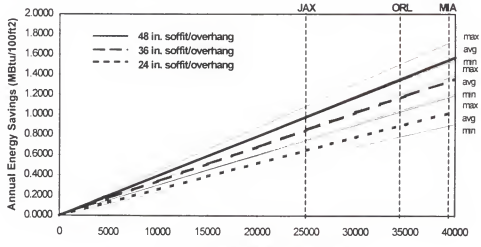

Figure 4.9. Reduced radiant heat soffit alternatives (16 in. soffit baseline).
* Subject to Southern Building Code (SBC) amendments to 110mph wind uplift.

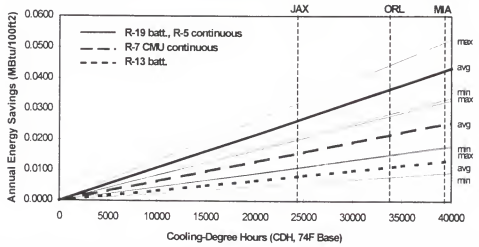

Figure 4.10. High-efficiency wall insulation alternatives (R-11 batt. stud, R-5 CMU baseline).

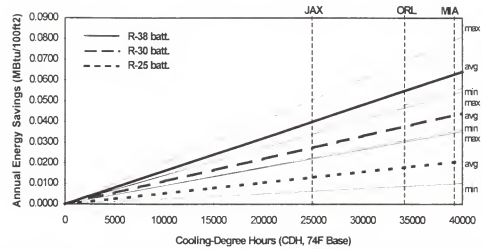

Figure 4.11. High-efficiency ceiling insulation alternatives (R-19 batt. baseline).

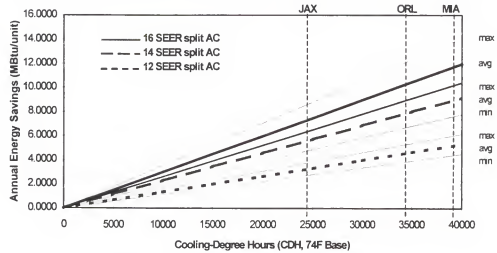

Figure 4.12. High-efficiency cooling alternatives (10 SEER Elec., 36-48KBtu split-AC baseline). SEER = Seasonal Energy Efficiency Rating.

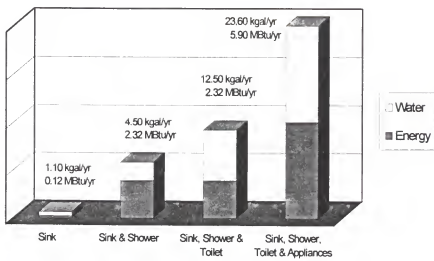

Figure 4.13. Watergy alternatives, annual savings.

Independent Energy and Watergy Straight-line ROI Simulation Summary

Straight-line ROI is the cost recovery of an alternative through energy and watergy resource conservation, assuming of course that an increase in capital cost is incurred. The straight-line approach subtracts the total capital cost increase of a sustainable alternative by the total value of resource savings over the estimated service life of the alternative to derive ROI_{max}, most often neglecting the amortized influences of interest rates, discounting, inflation and other "non-linear" future costs. By dividing the added capital cost of an alternative by the annual value of resource savings, a CCR or "breakeven" point is established. Similarly, ROI_{max}, can be divided by the increase in capital costs to determine the SIR of a given energy or watergy alternative.

In the examples provided in Tables 4.4 and 4.6, the average unit heating and cooling season reductions for the sustainable alternatives provided were multiplied by the respective CDHs and HDDs in the Orlando (central) region. The sum of the total heating and cooling season reductions represented the total energy reduction. The cost savings for the total energy and watergy reductions were calculated using the average utility rates found in Tables 4.16-4.18. Based on a given capital cost and average life-cycle cost savings, an ROI_{max}, CCR and SIR was determined for each sustainable energy and watergy alternative (Tables 4.5 and 4.7, Figures 4.14-4.20). Although the straight-line ROI approach is often used in industry as a decision tool, it is nevertheless limited in its ability to accurately model ROI in lieu of changing cost variables over time. As a result, straight-line ROI will only be used as a basis to 1) categorize sustainable energy and watergy alternatives into 10, 15, 20 and 25 year CCR packages and 2) prioritize alternatives within each CCR package by SIR. Once completed, more advanced models may be developed to fully account for the net present value of sustainable energy and watergy alternatives in lieu of non-uniform, non-linear cost changes over the service life of the alternative.

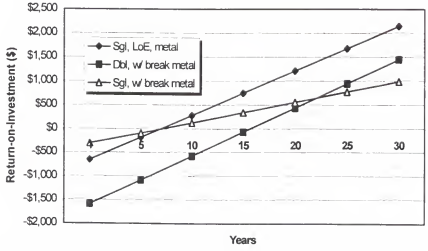

Figure 4.14. Energy efficient window alternatives (single pane, metal sash baseline), Orlando, FL.

Table 4.4. Independent energy and watergy performance simulation, glazing and wall insulation, Orlando, FL (34.0kCDH, 0.7kHDD).

Sustainable Alternatives	Item Unit	Total Energy Reduction ΔMBtuh/unit/yr (34.0kCDH, 0.7kHDD)	Cooling Season Energy Reduction ΔMBtuh/unit/yr/kCDH			Heating Season Energy Reduction ΔMBtuh/unit/yr/kHDD			Total Water Reduction Δkgal/unit/yr
		AVERAGE	Range	Mean	AvDev	Range	Mean	AvDev	
101 SGL/LoE Metal Windows	250 sf	3.5750	0.09-0.10	0.0957	0.0876	0.59-0.70	0.6356	0.0842	n/a
102 SGL w/ Break Metal Windows	250 sf	1.6650	0.03-0.05	0.0387	0.1726	0.59-0.70	0.6356	0.0842	n/a
103 DBL/LoE/Vinyl Windows	250 sf	7.8750	0.17-0.20	0.1865	0.0763	2.58-3.00	2.7492	0.0765	n/a
104 TRP/Vinyl Windows	250 sf	6.7750	0.14-0.16	0.1494	0.0726	2.71-3.21	2.8861	0.0870	n/a
105 DBL/LoE/Wood Windows	250 sf	7.6488	0.17-0.19	0.1814	0.0740	2.51-3.00	2.6725	0.0910	n/a
106 TRP/Wood Windows	250 sf	6.5129	0.13-0.15	0.1443	0.0706	2.64-3.00	2.7909	0.0635	n/a
107 DBL/Vinyl Windows	250 sf	5.7504	0.11-0.13	0.1224	0.0762	2.44-2.78	2.5674	0.0659	n/a
108 DBL/Wood Windows	250 sf	5.4938	0.11-0.13	0.1176	0.0740	2.38-2.78	2.5257	0.0801	n/a
109 DBL LoE w/ Break Windows	250 sf	6.3805	0.14-0.16	0.1494	0.0726	2.11-2.57	2.2856	0.0995	n/a
110 TRP w/ Break Metal Windows	250 sf	5.0968	0.10-0.12	0.1067	0.0911	2.25-2.57	2.3789	0.0678	n/a
111 DBL w/ Break Metal Windows	250 sf	3.8285	0.07-0.08	0.0758	0.1053	1.96-2.35	2.0786	0.0938	n/a
112 DBL Metal Windows	250 sf	2.1866	0.03-0.04	0.0381	0.1282	1.32-1.50	1.4081	0.0629	n/a
120 24in. Soffit	200 lf	3.4210	0.09-0.12	0.1034	0.1379	0.00-0.00	0.0000	0.0000	n/a
121 36in Soffit	200 lf	6.4413	0.18-0.23	0.2083	0.1219	-0.23-0.62	-0.4624	0.4145	n/a
122 48in. Soffit	200 lf	9.4103	0.27-0.35	0.3138	0.1214	-0.70-1.32	-1.0519	0.2955	n/a
201 R-19 Batt, R-5 Cont., 2x6 Frame	2,000 sf	1.3072	0.01-0.03	0.0202	0.3146	0.96-1.17	1.0222	0.1004	n/a
202 R-19 Batt, 2x6 Frame	2,000 sf	1.0019	0.01-0.02	0.0156	0.3357	0.69-0.78	0.7333	0.0608	n/a
203 R-13 Batt, R-5 Cont., 2x4 Frame	2,000 sf	0.9052	0.01-0.02	0.0131	0.4003	0.66-0.71	0.6896	0.0379	n/a
204 R-11 Batt, R-5 Cont., 2x4 Frame	2,000 sf	0.7934	0.01-0.02	0.0121	0.2725	0.55-0.70	0.5955	0.1267	n/a
205 R-13 Batt, 2x4 Frame	2,000 sf	0.3763	0.00-0.01	0.0067	0.5385	0.22-0.27	0.2467	0.1116	n/a

ΔMBtu/unit/yr/kCDH = change in energy load or consumption, million British thermal units per unit, per year, per thousand cooling degree hours.
ΔMBtu/unit/yr/kHDD = change in energy load or consumption, million British thermal units per unit, per year, per thousand heating degree days.
Δ kgal/unit/yr = change in water consumption, thousands of gallons per unit, per year.
Heating and Cooling Season Energy Reduction is average of plan-forms A and B modeled in north, central, and south Florida regions.
Total Energy Reduction is sum of Heating and Cooling Season Energy Reduction, Orlando, FL (34.0kCDH, 0.7kHDD)

Table 4.5. Independent energy and watergy "straight-line" ROI simulation, glazing and wall insulation, Orlando, FL.

Sustainable Alternatives	Item Unit	Δ CC	% Δ CC	ROI_{annual}	CCR	Service Life	ROI_{max}	SIR	SIR Ranking
101 SGL/LoE Metal Windows	250 sf	$650.00	50%	$93.13	6.98 years	30 year	$2,143.85	3.30	11
102 SGL w/ Break Metal Windows	250 sf	$307.30	23%	$43.25	7.11 years	30 year	$989.99	3.23	12
103 DBL/LoE/Vinyl Windows	250 sf	$1,350.00	104%	$207.45	6.51 years	30 year	$4,873.00	3.61	9
104 TRP/Vinyl Windows	250 sf	$2,345.00	180%	$178.34	13.15 years	30 year	$3,005.03	1.28	33
105 DBL/LoE/Wood Windows	250 sf	$4,204.58	323%	$216.88	19.39 years	30 year	$2,301.82	0.55	44
106 TRP/Wood Windows	250 sf	$5,147.49	396%	$172.35	29.80 years	30 year	$23.01	0.00	46
107 DBL/Vinyl Windows	250 sf	$1,100.00	85%	$151.11	7.28 years	30 year	$3,433.22	3.12	13
108 DBL/Wood Windows	250 sf	$3,848.95	296%	$144.95	26.55 years	30 year	$500.08	0.13	45
109 DBL LoE w/ Break Windows	250 sf	$1,992.49	153%	$167.27	11.91 years	30 year	$3,025.92	1.52	31
110 TRP w/ Break Metal Windows	250 sf	$2,312.00	177%	$133.80	17.28 years	30 year	$1,701.94	0.74	41
111 DBL w/ Break Metal Windows	250 sf	$1,588.33	122%	$101.30	15.68 years	30 year	$1,450.62	0.91	39
112 DBL Metal Windows	250 sf	$631.45	49%	$57.75	10.93 years	30 year	$1,101.30	1.75	28
120 24in. Soffit	200 lf	$832.00	139%	$29.68	28.03 years	50 year	$652.07	0.78	40
121 36in Soffit	200 lf	$1,670.00	228%	$75.50	22.27 years	50 year	$2,093.62	1.26	34
122 48in. Soffit	200 lf	$2,496.00	416%	$144.66	17.25 years	50 year	$4,737.62	1.90	22
201 R-19 Batt, R-5 Cont., 2x6	2,000 sf	$808.73	220%	$34.00	23.79 years	50 year	$891.14	1.10	38
202 R-19 Batt, 2x6	2,000 sf	$447.06	149%	$26.00	17.19 years	50 year	$853.06	1.91	21
203 R-13 Batt, R-5 Cont., 2x4	2,000 sf	$411.67	137%	$23.80	17.27 years	50 year	$778.97	1.89	23
204 R-11 Batt, R-5 Cont., 2x4	2,000 sf	$361.67	121%	$20.40	17.73 years	50 year	$658.31	1.82	24
205 R-13 Batt, 2x4 Frame	2,000 sf	$50.00	17%	$9.80	5.10 years	50 year	$440.02	8.86	4

Table 4.6. Independent energy and watergy performance simulation, ceiling insulation, HVAC and appliances, Orlando, FL (340.kCDH, 0.7kHDD).

Sustainable Alternatives	Item Unit	Total Energy Reduction ΔMBtuh/unit/yr (34.0kCDH, 0.7kHDD)	Cooling Season Energy Reduction ΔMBtuh/unit/yr/kCDH			Heating Season Energy Reduction ΔMBtuh/unit/yr/kHDD			Total Water Reduction Δkgal/unit/yr
		AVERAGE	Range	Mean	AvDev	Range	Mean	AvDev	
301 R-25, 8" Ceiling	2,000 sf	0.4507	0.00-0.02	0.0103	0.6128	0.00-0.21	0.1123	0.9366	n/a
302 R-30, 10" Ceiling	2,000 sf	0.7436	0.01-0.03	0.0197	0.3508	0.00-0.30	0.1619	0.9180	n/a
303 R-35, 12" Ceiling	2,000 sf	0.9246	0.02-0.03	0.0241	0.3566	0.00-0.42	0.2494	0.8436	n/a
304 R-38, 12" Ceiling	2,000 sf	1.0825	0.02-0.04	0.0272	0.4223	0.00-0.42	0.2742	0.7674	n/a
401 7 HSPF/12 SEER ASHP	1 ea	4.9000	0.11-0.15	0.1326	0.1562	0.86-1.07	0.9739	0.1099	n/a
402 7 HSPF/14 SEER ASHP	1 ea	7.9667	0.19-0.27	0.2288	0.1639	0.86-1.07	0.9739	0.1099	n/a
403 8 HSPF/16 SEER ASHP	1 ea	10.7667	0.25-0.35	0.2987	0.1656	1.15-1.85	1.6893	0.1004	n/a
404 90 AFUE/12 SEER Split Gas	1 ea	5.7667	0.10-0.15	0.1277	0.1967	2.07-2.35	2.2041	0.0647	n/a
405 90 AFUE/14 SEER Split Gas	1 ea	8.8333	0.19-0.27	0.2288	0.1639	2.07-2.35	2.2041	0.0647	n/a
406 95 AFUE/16 SEER Split Gas	1 ea	11.7167	0.25-0.35	0.2987	0.1656	2.88-3.35	3.1222	0.0758	n/a
407 Programmable Thermostat	1 ea	1.0000	0.02-0.03	0.0265	0.1862	0.15-0.42	0.2541	0.5440	n/a
501 Indoor Compact Fluorescent	15 ea	0.1001	n/a	n/a	n/a	n/a	n/a	n/a	n/a
502 Electric DHW, R-5 Blanket	1 ea	0.3167	n/a	n/a	n/a	n/a	n/a	n/a	n/a
503 Gas Instant DHW	1 ea	4.0333	n/a	n/a	n/a	n/a	n/a	n/a	n/a
504 Gas DWH, R-5 Blanket	1 ea	1.8167	n/a	n/a	n/a	n/a	n/a	n/a	n/a
505 Solar DHW	1 ea	10.5161	n/a	n/a	n/a	n/a	n/a	n/a	n/a
506 Natural Gas Clothes Dryer	1 ea	-4.1833	n/a	n/a	n/a	n/a	n/a	n/a	n/a
507 Natural Gas Range-Oven	1 ea	-2.9833	n/a	n/a	n/a	n/a	n/a	n/a	n/a
601 Low-flow Toilet Fixtures	2 ea	0.000	n/a	n/a	n/a	n/a	n/a	n/a	8.00-10.00
602 Low-flow Shower Fixtures	2 ea	2.205	n/a	n/a	n/a	n/a	n/a	n/a	4.40-5.20
603 Low-flow Sink Fixtures	3 ea	0.115	n/a	n/a	n/a	n/a	n/a	n/a	1.00-1.10
604 Low-flow Clothes Washer	1 ea	0.680	n/a	n/a	n/a	n/a	n/a	n/a	5.65-5.90
605 Low-flow Dishwasher	1 ea	2.885	n/a	n/a	n/a	n/a	n/a	n/a	4.50-4.75

ΔMBtu/unit/yr/kCDH = change in energy load or consumption, million British thermal units per unit, per year, per thousand cooling degree hours.
ΔMBtu/unit/yr/kHDD = change in energy load or consumption, million British thermal units per unit, per year, per thousand heating degree days.
Δ kgal/unit/yr = change in water consumption, thousands of gallons per unit, per year.
Heating and Cooling Season Energy Reduction is average of plan-forms A and B modeled in north, central, and south Florida regions.
Total Energy Reduction is sum of Heating and Cooling Season Energy Reduction, Orlando, FL (34.0kCDH, 0.7kHDD)

Table 4.7. Independent energy and watergy "straight-line" ROI simulation, ceiling insulation, HVAC and appliances, Orlando, FL.

Sustainable Alternatives	Item Unit	Δ CC	% Δ CC	ROI_{annual}	CCR	Service Life	ROI_{max}	SIR	SIR Ranking
301 R-25, 8" Ceiling	2,000 sf	$171.05	37%	0.0690	14.49 years	50 year	$419.02	2.45	16
302 R-30, 10" Ceiling	2,000 sf	$296.75	65%	0.0660	15.14 years	50 year	$683.26	2.30	18
303 R-35, 12" Ceiling	2,000 sf	$461.05	100%	0.0542	18.44 years	50 year	$789.00	1.71	29
304 R-38, 12" Ceiling	2,000 sf	$511.05	111%	0.0536	18.65 years	50 year	$858.99	1.68	30
305 Radiant Barrier	2,000 sf	$348.00	36%	0.0690	14.50 years	50 year	$852.00	2.45	17
401 7 HSPF/12 SEER ASHP	1 ea	$300.00	15%	0.4317	2.33 years	15 year	$1,628.10	5.48	6
402 7 HSPF/14 SEER ASHP	1 ea	$550.00	26%	0.3751	2.67 years	15 year	$2,544.05	4.63	7
403 8 HSPF/16 SEER ASHP	1 ea	$1,500.00	67%	0.1866	5.36 years	15 year	$2,697.45	1.80	25
404 90 AFUE/12 SEER Split Gas	1 ea	$1,150.00	58%	0.1113	8.98 years	15 year	$770.56	0.67	42
405 90 AFUE/14 SEER Split Gas	1 ea	$1,400.00	70%	0.1468	6.81 years	15 year	$1,683.05	1.20	36
406 95 AFUE/16 SEER Split Gas	1 ea	$2,800.00	140%	0.1089	9.18 years	15 year	$1,775.00	0.63	43
407 Programmable Thermostat	1 ea	$125.00	6%	0.2106	4.75 years	15 year	$269.88	2.16	19
501 Indoor Compact Fluorescent	15 ea	$162.00	35%	0.2778	3.60 years	10 years	$288.00	1.77	26
502 Electric DHW, R-5 Blanket	1 ea	$6.99	4%	1.1657	0.86 years	15 years	$115.38	16.49	1
503 Gas Instant DHW	1 ea	$190.00	119%	0.2351	4.25 years	15 years	$479.90	2.53	15
504 Gas DWH, R-5 Blanket	1 ea	$390.00	244%	0.3346	2.99 years	15 years	$1,561.49	4.02	8
505 Solar DHW	1 ea	$1,326.00	379%	0.2193	4.56 years	10 years	$1,577.60	1.19	37
506 Natural Gas Clothes Dryer	1 ea	$94.00	37%	0.2428	4.08 years	10 years	$135.43	1.45	32
507 Natural Gas Range-Oven	1 ea	$73.00	21%	0.2421	4.12 years	15 years	$192.14	2.63	14
601 Low-flow Toilet Fixtures	2 ea	$64.22	45%	0.8488	1.18 years	15 years	$964.83	11.73	3
602 Low-flow Shower Fixtures	2 ea	$43.00	31%	1.6323	0.61 years	10 years	$659.08	15.32	2
603 Low-flow Sink Fixtures	3 ea	$35.40	29%	0.2749	3.68 years	10 years	$60.80	1.75	27
604 Low-flow Clothes Washer	1 ea	$111.00	28%	0.4377	2.28 years	10 years	$375.04	3.38	10
605 Low-flow Dishwasher	1 ea	$140.00	28%	0.7849	1.27 years	10 years	$959.34	6.85	5

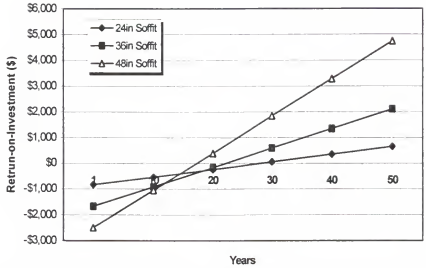

Figure 4.15. Reduced radiant heat soffit alternatives (16 in. soffit baseline), Orlando, FL.

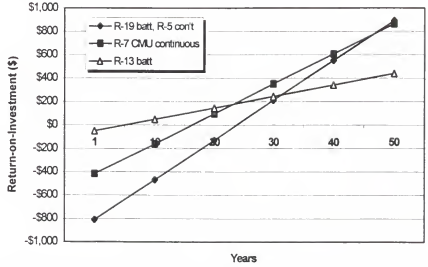

Figure 4.16. High-efficiency wall insulation alternatives (R-11 batt. stud, R-5 CMU baseline), Orlando, FL.

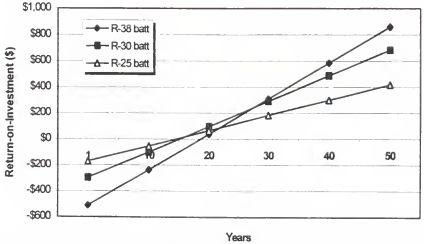

Figure 4.17. High-efficiency ceiling insulation alternatives (R-19 batt. baseline), Orlando, FL.

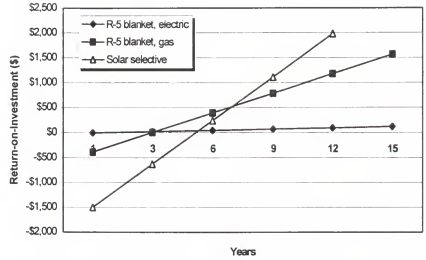

Figure 4.18. High-efficiency water heating alternatives (0.91EFF Electric, 100 gal. baseline), Orlando, FL.

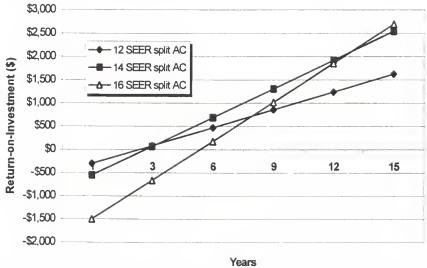

Figure 4.19. High-efficiency cooling alternatives (10 SEER, 36kBtu ASHP baseline), Orlando, FL.

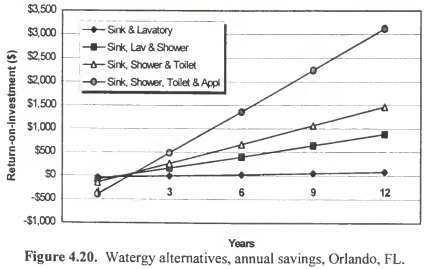

Figure 4.20. Watergy alternatives, annual savings, Orlando, FL.

Independent Energy and Watergy ROI Prioritization Summary

Prior to an integrated performance simulation (i.e., assessing the life-cycle performance of several energy and watergy alternatives simultaneously), it was necessary to prioritize alternatives based on the straight-line ROI simulation. Prioritization was necessary because the order that sustainable alternatives were introduced to the integrated performance simulation model had a significant effect on the performance and subsequent ROI of each alternative. Improvements in thermal envelope for instance, have been demonstrated to reduce the operation time of high SEER air-source heat pump (ASHP) systems, thereby reducing the maximum performance benefits possible and thus reducing the heat pump ROI. Research has shown that most thermal energy systems have a negative synergistic effect, whereby the marginal benefits of each added sustainable improvement decline as the number of total improvements increase, otherwise referred to as a function of *declining marginal utility*. Water systems however, have an *additive* effect whereby the marginal benefits of each improvement are not affected as the number of improvements increase. In summary, the performance of each sustainable energy and watergy alternative was modeled, individually, using the 1995 MEC baseline for each plan-form. The "straight-line" ROI_{max}, CCR and SIR was then determined, and each alternative was subsequently 1) selected according to ROI_{max}, 2) categorized according to CCR at 5 year intervals and 3) prioritized in descending order by SIR.

Integrated Energy and Watergy Performance Simulation Summary

Once the individual performance and subsequent ROI of each sustainable energy and watergy alternative had been assessed and prioritized using the baseline characteristics of each region and plan-form, an integrated performance simulation was possible. Alternatives were selected by ROI_{max} and prioritized by savings-to-investment ratio (SIR) because consumers demonstrated a willingness-to-pay for higher initial cost alternatives based on higher total returns than any other cost or non-cost related factor (38.1-48.4%, $r = 0.90$). As Table 4.8 illustrates, fifteen sustainable glazing alternatives exceeded 1995 MEC standards, yet only double-pane LoE vinyl windows were selected for the 10 year CCR package. Of the four glazing alternatives that achieved CCR in 10 years or less (Table 4.5), double-pane LoE vinyl windows provided the highest ROI_{max}. However, double-pane LoE windows appear fifth in the prioritization because four of the other non-glazing alternatives in the 10 year CCR package achieved a higher SIR. For example, integrating R-13 into the simulation model before double-pane LoE glazing reduces the window unit energy savings from 7.8 to 7.63 MBtu/yr. As Tables 4.8-4.11 and Figures 4.21–4.23 illustrate, the integrated energy savings of cumulative energy alternatives is often less than the sum of energy savings from alternatives modeled individually.

Table 4.8. Integrated energy and watergy performance simulation, 10 year CCR package, Orlando, FL (34.0kCDH, 0.7kHDD).

Sustainable Alternatives	Item Unit	Independent Energy Reduction (Δ MBtuh/unit/yr)		Integrated Energy Reduction (Δ MBtuh/unit/yr)		Total Water Reduction (Δkgal/unit/yr)	
		Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	1.40	1.40	1.40	1.40	8.00	8.00
601 Low-flow toilet fixtures	2ea	0.00	1.40	0.00	1.40	4.40	12.40
205 R-13 batt wall insulation	2000sf	0.40	1.80	0.40	1.80	0.00	12.40
605 Low-flow dishwasher	1ea	2.90	4.70	2.90	4.70	4.50	16.90
103 DBL/LoE vinyl windows	250ea	7.80	12.50	7.63	12.33	0.00	16.90
604 Low-flow clothes washer	1ea	0.70	13.20	0.70	13.03	5.65	22.55
407 Programmable thermostat	1ea	1.00	14.20	0.82	13.85	0.00	22.55
403 8 HSPF/16 SEER ASHP	1ea	10.70	24.90	7.92	21.76	0.00	22.55
501 Indoor compact fluorescent	15ea	1.50	26.40	1.00	22.76	0.00	22.55
603 Low-flow sink and lavatory	3ea	0.03	26.43	0.03	22.80	1.00	23.55
505 Solar DHW	1ea	10.50	36.93	6.92	29.71	0.00	23.55

Table 4.9. Integrated energy and watergy performance simulation, 15 year CCR package, Orlando, FL (34.0kCDH, 0.7kHDD).

Sustainable Alternatives	Item Unit	Independent Energy Reduction (Δ MBtuh/unit/yr)		Integrated Energy Reduction (Δ MBtuh/unit/yr)		Total Water Reduction (Δkgal/unit/yr)	
		Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	1.40	1.40	1.40	1.40	4.40	4.40
601 Low-flow toilet fixtures	2ea	0.00	1.40	0.00	1.40	8.00	12.40
205 R-13 batt wall insulation	2000sf	0.40	1.80	0.40	1.80	0.00	12.40
605 Low-flow dishwasher	1ea	2.90	4.70	2.90	4.70	4.50	16.90
103 DBL/LoE vinyl windows	250sf	7.80	12.50	7.63	12.33	0.00	16.90
604 Low-flow clothes washer	1ea	0.70	13.20	0.70	13.03	5.65	22.55
301 R-25, 8" ceiling insulation	2000sf	0.45	13.65	0.40	13.43	0.00	22.55
407 Programmable thermostat	1ea	1.00	14.65	0.68	14.11	0.00	22.55
403 8 HSPF/16 SEER ASHP	1ea	10.70	22.35	7.72	21.83	0.00	22.55
501 Indoor compact fluorescent	15ea	1.50	26.85	1.00	22.83	0.00	22.55
603 Low-flow sink and lavatory	3ea	0.03	26.88	0.03	22.86	1.00	23.55
505 Solar DHW	1ea	10.50	37.38	6.92	29.78	0.00	23.55

Table 4.10. Integrated energy and watergy performance simulation, 20 year CCR package, Orlando, FL (34.0kCDH, 0.7kHDD).

Sustainable Alternatives	Item Unit	Independent Energy Reduction (Δ MBtuh/unit/yr)		Integrated Energy Reduction (Δ MBtuh/unit/yr)		Total Water Reduction (Δkgal/unit/yr)	
		Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	1.40	1.40	1.40	1.40	4.40	4.40
601 Low-flow toilet fixtures	2ea	0.00	1.40	0.00	1.40	8.00	12.40
605 Low-flow dishwasher	1ea	2.90	4.30	2.90	4.30	4.50	16.90
103 DBL/LoE vinyl windows	250sf	7.80	12.10	7.50	11.80	0.00	16.90
604 Low-flow clothes washer	1ea	0.70	12.80	0.70	12.50	5.65	22.55
407 Programmable thermostat	1ea	1.50	14.30	0.80	13.30	0.00	22.55
202 R-19 batt wall insulation	2000sf	1.01	15.31	1.00	14.30	0.00	22.55
122 48in soffit	200lf	5.36	20.67	4.21	18.51	0.00	22.55
403 8 HSPF/16 SEER ASHP	1ea	10.70	31.37	5.30	23.81	0.00	22.55
501 Indoor compact fluorescent	15ea	1.50	32.87	0.07	23.88	0.00	22.55
603 Low-flow sink and lavatory	3ea	0.03	32.90	0.03	23.91	1.00	23.55
304 R-38 batt ceiling insulation	2000sf	1.08	33.98	0.80	24.71	0.00	23.55
505 Solar DHW	1ea	10.50	44.48	6.92	31.63	0.00	23.55

Table 4.11. Integrated energy and watergy performance simulation, 25 year CCR package, Orlando, FL (34.0kCDH, 0.7kHDD).

Sustainable Alternatives	Item Unit	Independent Energy Reduction (Δ MBtuh/unit/yr)		Integrated Energy Reduction (Δ MBtuh/unit/yr)		Total Water Reduction (Δkgal/unit/yr)	
		Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	1.40	1.40	1.40	1.40	4.40	4.40
601 Low-flow toilet fixtures	2ea	0.00	1.40	0.00	1.40	8.00	12.40
605 Low-flow dishwasher	1ea	2.90	4.30	2.90	4.30	4.50	16.90
103 DBL/LoE vinyl windows	250sf	7.80	12.10	7.50	11.80	0.00	16.90
604 Low-flow clothes washer	1ea	0.70	12.80	0.70	12.50	5.65	22.55
407 Programmable thermostat	1ea	1.50	14.30	0.80	13.30	0.00	22.55
122 48in soffit	200lf	5.36	19.66	4.21	17.51	0.00	22.55
403 8 HSPF/16 SEER ASHP	1ea	10.70	30.36	5.73	23.24	0.00	22.55
501 Indoor compact fluorescent	15ea	1.50	31.86	1.00	24.24	0.00	22.55
603 Low-flow sink and lavatory	3ea	0.03	31.89	0.03	24.28	1.00	23.55
304 R-38 batt ceiling insulation	2000sf	1.08	32.97	0.94	25.22	0.00	23.55
505 Solar DHW	1ea	10.50	43.47	6.92	32.13	0.00	23.55
201 R-19 batt, R-5 con't wall insulation	2000sf	1.31	44.78	1.00	33.13	0.00	23.55

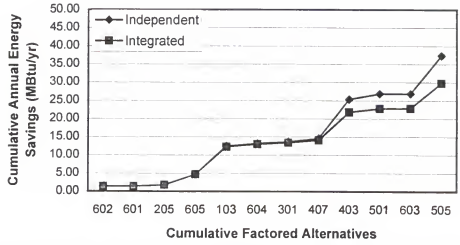

Figure 4.21. Comparison of independent and integrated cumulative annual energy savings of sustainable energy and watergy alternatives, 15 year CCR package.

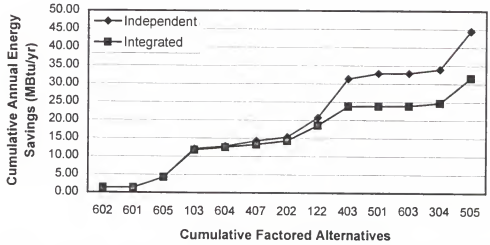

Figure 4.22. Comparison of independent and integrated cumulative annual energy savings of sustainable energy and watergy alternatives, 20 year CCR package.

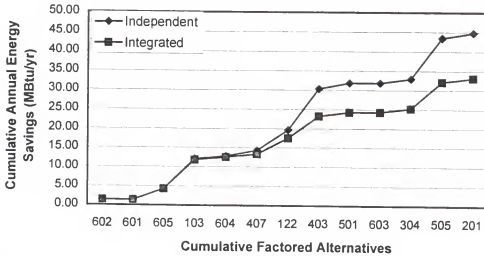

Figure 4.23. Comparison of independent and integrated cumulative annual energy savings of sustainable energy and watergy alternatives, 25 year CCR package.

Integrated Energy and Watergy Straight-line ROI Simulation Summary

Following the integrated performance simulation modeling, it was once again necessary to assess the cost-benefit of the capital cost and life-cycle ROI for each applicable alternative, now as a part of an integrated system of several other combinations of sustainable alternatives. Data from the integrated performance simulation were used to compute incremental changes in the total cumulative ROI relative to changes in ROI for each existing and new alternative included within the data set. The results of the integrated performance simulation are summarized below (Figures 4.24-4.31 and Tables 4.12-4.15)

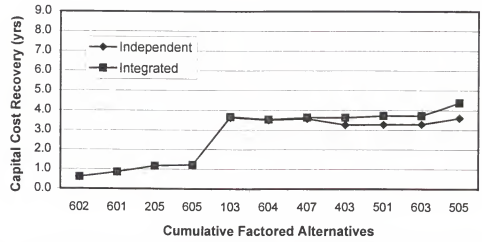

Figure 4.24. Comparison of independent and integrated cumulative *capital cost recovery* of sustainable energy and watergy alternatives, 10 year CCR package.

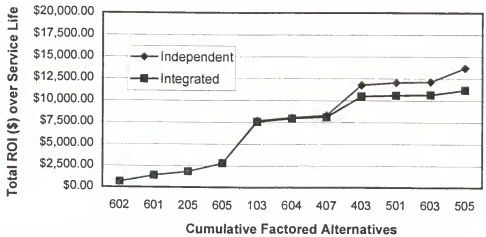

Figure 4.25. Comparison of independent and integrated cumulative *maximum ROI* of sustainable energy and watergy alternatives, 10 year CCR package.

Table 4.12. Integrated energy and watergy "straight-line" ROI simulation, 10 year CCR package, Orlando, FL.

Sustainable Alternatives	Item Unit	Independent Capital Cost Recovery (years)		Integrated Capital Cost Recovery (years)		Independent ROI_{ss} over Service Life		Integrated ROI_{ss} over Service Life	
		Item	Cumulative	Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	0.61	0.61	0.61	0.61	$658.90	$658.90	$658.90	$658.90
601 Low-flow toilet fixtures	2ea	1.18	0.86	1.18	0.86	$753.43	$1,411.43	$753.43	$1,411.43
205 R-13 batt wall insulation	2000sf	5.10	1.17	5.10	1.17	$440.00	$1,851.43	$440.00	$1,851.43
605 Low-flow dishwasher	1ea	1.27	1.22	1.27	1.22	$958.90	$2,810.33	$958.90	$2,810.33
103 DBL/LoE vinyl windows	250sf	6.51	3.65	6.63	3.68	$4,873.50	$7,683.83	$4,761.00	$7,571.33
604 Low-flow clothes washer	1ea	2.28	3.51	2.28	3.54	$374.80	$8,058.63	$374.80	$7,946.13
407 Programmable thermostat	1ea	4.75	3.58	6.20	3.64	$269.95	$8,328.58	$177.55	$8,123.68
403 8 HSPF/16 SEER ASHP	1ea	2.68	3.26	3.62	3.64	$3,447.45	$11,776.03	$2,357.55	$10,481.23
501 Indoor compact fluorescent	15ea	3.60	3.28	6.07	3.72	$288.00	$12,064.03	$105.00	$10,586.23
603 Low-flow sink and lavatory	3ea	3.68	3.29	3.68	3.72	$60.80	$12,124.83	$60.80	$10,647.03
505 Solar DHW	1ea	4.57	3.61	7.02	4.38	$1,574.00	$13,698.83	$562.30	$11,209.33

Table 4.13. Integrated energy and watergy "straight-line" ROI simulation, 15 year CCR package, Orlando, FL.

Sustainable Alternatives	Item Unit	Independent Capital Cost Recovery (years)		Integrated Capital Cost Recovery (years)		Independent ROI_{ss} over Service Life		Integrated ROI_{ss} over Service Life	
		Item	Cumulative	Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	0.61	0.61	0.61	0.61	$658.90	$658.90	$658.90	$658.90
601 Low-flow toilet fixtures	2ea	1.18	0.86	1.18	0.86	$753.43	$1,411.43	$753.43	$1,411.43
205 R-13 batt wall insulation	2000sf	5.10	1.17	5.10	1.17	$440.00	$1,851.43	$440.00	$1,851.43
605 Low-flow dishwasher	1ea	1.27	1.22	1.27	1.22	$958.90	$2,810.33	$958.90	$2,810.33
103 DBL/LoE vinyl windows	250sf	6.51	3.65	6.63	3.68	$4,873.50	$7,683.83	$4,761.00	$7,571.33
604 Low-flow clothes washer	1ea	2.28	3.51	2.28	3.54	$374.80	$8,058.63	$374.80	$7,946.13
301 R-25, 8" ceiling insulation	2000sf	14.50	3.77	14.75	3.80	$418.95	$8,477.58	$408.95	$8,355.08
407 Programmable thermostat	1ea	4.75	3.81	6.76	3.90	$269.95	$8,747.53	$152.50	$8,507.58
403 8 HSPF/16 SEER ASHP	1ea	2.68	3.43	3.75	3.86	$3,447.45	$12,194.98	$2,252.55	$10,760.13
501 Indoor compact fluorescent	15ea	3.60	3.44	6.00	3.93	$288.00	$12,482.98	$108.00	$10,868.13
603 Low-flow sink and lavatory	3ea	3.68	3.44	3.68	3.93	$60.80	$12,543.78	$60.80	$10,928.93
505 Solar DHW	1ea	4.57	3.72	7.02	4.54	$1,574.00	$14,117.78	$562.30	$11,491.23

Table 4.14. Integrated energy and watergy "straight-line" ROI simulation, 20 year CCR package, Orlando, FL.

Sustainable Alternatives	Item Unit	Independent Capital Cost Recovery (years)		Integrated Capital Cost Recovery (years)		Independent ROI_{ann} over Service Life		Integrated ROI_{ann} over Service Life	
		Item	Cumulative	Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	0.61	0.61	0.61	0.61	$658.90	$658.90	$658.90	$658.90
601 Low-flow toilet fixtures	2ea	1.18	0.86	1.18	0.86	$753.43	$1,411.43	$753.43	$1,411.43
605 Low-flow dishwasher	1ea	1.27	1.05	1.27	1.05	$958.90	$2,370.33	$958.90	$2,370.33
103 DBL/LoE vinyl windows	250sf	6.51	3.61	6.51	3.61	$4,873.50	$7,243.83	$4,873.50	$7,243.83
604 Low-flow clothes washer	1ea	2.28	3.48	2.28	3.48	$374.80	$7,618.63	$374.80	$7,618.63
407 Programmable thermostat	1ea	4.75	3.55	6.10	3.59	$269.95	$7,888.58	$182.50	$7,801.13
202 R-19 batt wall insulation	2000sf	17.19	4.20	18.32	4.26	$852.94	$8,741.52	$772.94	$8,574.07
122 48in soffit	200lf	17.25	6.95	21.97	7.36	$4,737.00	$13,478.52	$3,184.50	$11,758.57
403 8 HSPF/16 SEER ASHP	1ea	2.68	5.71	5.18	6.96	$3,447.45	$16,925.97	$1,422.45	$13,181.02
501 Indoor compact fluorescent	15ea	3.60	5.62	6.10	6.93	$288.00	$17,213.97	$103.50	$13,284.52
603 Low-flow sink and lavatory	3ea	3.68	5.60	3.68	6.89	$60.80	$17,274.77	$60.80	$13,345.32
304 R-38 batt ceiling insulation	2000sf	18.65	5.94	29.37	7.36	$858.95	$18,133.72	$358.95	$13,704.27
505 Solar DHW	1ea	4.57	5.64	7.02	7.30	$1,574.00	$19,707.72	$562.30	$14,266.57

Table 4.15. Integrated energy and watergy "straight-line" ROI simulation, 25 year CCR package, Orlando, FL.

Sustainable Alternatives	Item Unit	Independent Capital Cost Recovery (years)		Integrated Capital Cost Recovery (years)		Independent ROI_{ann} over Service Life		Integrated ROI_{ann} over Service Life	
		Item	Cumulative	Item	Cumulative	Item	Cumulative	Item	Cumulative
602 Low-flow shower fixtures	2ea	0.61	0.61	0.61	0.61	$658.90	$658.90	$658.90	$658.90
601 Low-flow toilet fixtures	2ea	1.18	0.86	1.18	0.86	$753.43	$1,411.43	$753.43	$1,411.43
605 Low-flow dishwasher	1ea	1.27	1.05	1.27	1.05	$958.90	$2,370.33	$958.90	$2,370.33
103 DBL/LoE vinyl windows	250sf	6.51	3.61	6.51	3.61	$4,873.50	$7,243.83	$4,873.50	$7,243.83
604 Low-flow clothes washer	1ea	2.28	3.48	2.28	3.48	$374.80	$7,618.63	$374.80	$7,618.63
407 Programmable thermostat	1ea	4.75	3.55	6.10	3.59	$269.95	$7,888.58	$182.50	$7,801.13
122 48in soffit	200lf	17.25	6.54	21.97	6.93	$4,737.00	$12,625.58	$3,184.50	$10,985.63
403 8 HSPF/16 SEER ASHP	1ea	2.68	5.40	5.18	6.60	$3,447.45	$16,073.03	$1,422.45	$12,408.08
501 Indoor compact fluorescent	15ea	3.60	5.31	6.10	6.58	$288.00	$16,361.03	$103.50	$12,511.58
603 Low-flow sink and lavatory	3ea	3.68	5.30	3.68	6.55	$60.80	$16,421.83	$60.80	$12,572.38
304 R-38 batt ceiling insulation	2000sf	18.65	5.66	29.37	7.03	$858.95	$17,280.78	$358.95	$12, 931.33
505 Solar DHW	1ea	4.57	5.42	7.02	7.03	$1,574.00	$18,854.78	$562.30	$13,493.63
201 R-19 batt, R-5 con't wall insulation	2000sf	23.79	5.88	24.66	7.58	$891.27	$19,746.05	$831.27	$14,324.90

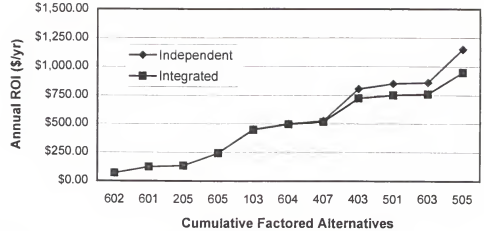

Figure 4.26. Comparison of independent and integrated cumulative *annual ROI* of sustainable energy and watergy alternatives, 15 year CCR package.

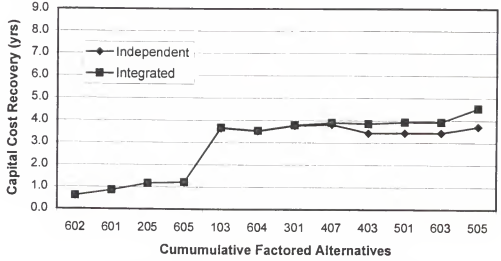

Figure 4.27. Comparison of independent and integrated cumulative *capital cost recovery* of sustainable energy and watergy alternatives, 15 year CCR package.

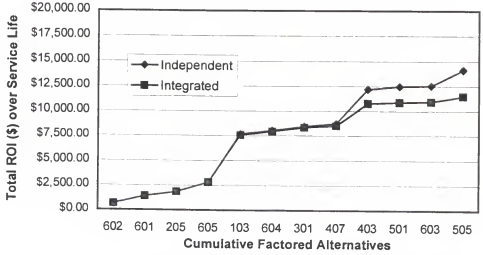

Figure 4.28. Comparison of independent and integrated cumulative *maximum ROI* of sustainable energy and watergy alternatives, 15 year CCR package.

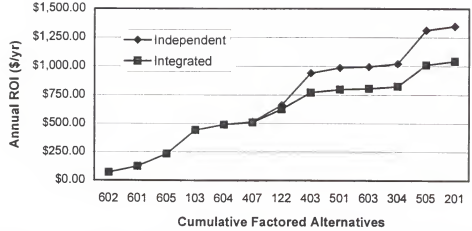

Figure 4.29. Comparison of independent and integrated cumulative *annual ROI* of sustainable energy and watergy alternatives, 25 year CCR package.

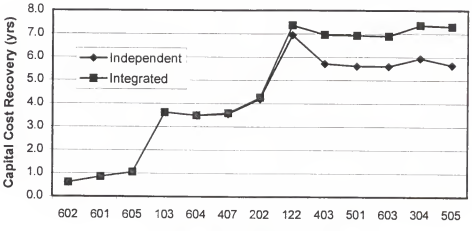

Figure 4.30. Comparison of independent and integrated cumulative *capital cost recovery* of sustainable energy and watergy alternatives, 25 year CCR package.

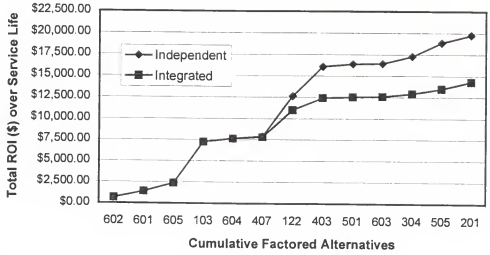

Figure 4.31. Comparison of independent and integrated cumulative *maximum ROI* of sustainable energy and watergy alternatives, 25 year CCR package.

ROI Amortized Cost Variable Simulation Summary

The primary objective of this sixth and final life-cycle cost modeling section is to integrate amortization into the previous straight-line processes to provide a more realistic account for changes in cost-benefit over time. Net present value (NPV) is a term given to the present worth of a sustainable alternative based on its capital cost and its non-linear payback as a function of changing interest rates, resource costs and uncertainty discounted over the service life of the alternative. Using the actual energy and watergy resource rates from Orlando, Florida, Figure 4.32 shows the changes in SIR and CCR relative to changes in discount rates using the *integrated* 15 year CCR package from Table 4.13 as an example. The discount rates simulated below indicate the change in energy and watergy rates relative to the change in general inflation over time. A "4%" discount rate for example, implies that energy inflation will be "discounted" an average of 4% below the rate of general inflation per year, decreasing the value of added energy and watergy performance over time. A "-4%" discount rate implies that energy inflation will remain an average of 4% above the rate of general inflation per year, thus increasing the value of added energy and watergy performance. A second order polynomial regression line is provided to illustrate the drastic changes in CCR and SIR relative to each 4% and –4% discount rates. The three digit label codes represent respective energy and watergy alternatives.

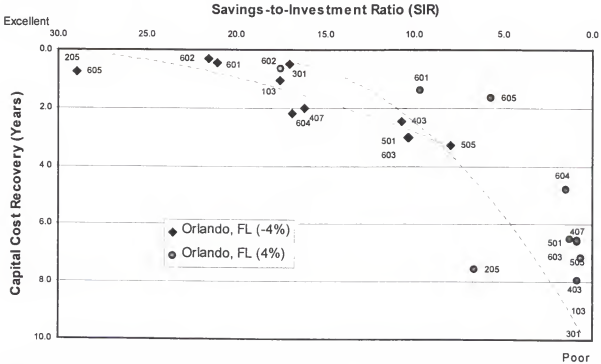

Figure 4.32. Change in payback period and SIR relative to change in discount rates, 15 year CCR package, Orlando, Florida. Note number codes represent respective energy and watergy alternatives (refer to Tables 4.5 – 4.15).

Table 4.16. Regional electricity rates, $/kWh

City-Region	Base	Rank	City	Rank	County	Rank
Jacksonville - North Region	$0.07	1	$0.08	1	$0.08	1
Orlando - Central Region	$0.08	5	$0.09	5	$0.09	4
Miami - South Region	$0.08	7	$0.09	7	$0.09	7
Average	$0.08	n/a	$0.09	n/a	$0.09	n/a
Total Average	$0.09					

Table 4.17. Regional combined domestic water and wastewater rates, $/1000gal

City-Region	Base	City	County
Jacksonville - North Region	$6.60	$6.85	$6.85
Orlando - Central Region	$6.35	$6.50	$6.75
Miami - South Region	$4.65	$4.85	$5.05
Average	$5.90	$6.10	$6.25
Total Average	$6.09		

Table 4.18. Regional capital cost adjustment factors.

City-Region	U.S.	Florida
Jacksonville - North Region	0.796	0.942
Orlando - Central Region	0.845	1.000
Miami - South Region	0.531	0.730

Table 4.19. Fuel escalation rates (24).

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Electric	1.00	1.01	1.02	1.03	1.02	0.99	0.99	0.97	0.97	0.99	0.99	1.01	1.02
Oil	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.04	1.06	1.08	1.11	1.04
Propane	1.00	0.96	0.95	0.93	0.92	0.92	0.92	0.92	0.94	0.95	0.97	0.99	1.02
Natural Gas	1.00	1.02	1.03	1.04	1.04	1.04	1.04	1.05	1.08	1.12	1.16	1.22	1.27
Kerosene	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4.19. Fuel escalation rates (continued) (24).

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Electric	**1.02**	**1.03**	**1.04**	**1.05**	**1.05**	**1.06**	**1.06**	**1.07**	**1.07**	**1.08**	**1.08**	**1.08**	**1.09**
Oil	1.17	1.20	1.22	1.24	1.26	1.27	1.28	1.30	1.35	1.35	1.37	1.40	1.41
Propane	1.04	1.06	1.08	1.10	1.11	1.12	1.13	1.15	1.17	1.19	1.21	1.29	1.25
Natural Gas	1.30	1.36	1.40	1.44	1.45	1.49	1.51	1.54	1.57	1.60	1.62	1.65	1.67
Kerosene	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Using the projected energy escalation rates from Table 4.19 above, variable discount rates were computed and applied to the cost-benefit modeling for each region. Regional resource rates and capital cost adjustment factors were implemented from Tables 4.16-4.18, providing the most realistic prediction of the NPV of energy and watergy savings. Although the same DOE variable discount rate was used for each energy and watergy alternative in each region, Figure 4.33 and Table 4.20 illustrate the end cost-benefit differences that remain between regions as a result of subtle climatic variance (<9° latitute, <2° longitude), resource rates and adjusted capital costs, as well as the ever present declining marginal utility trend as cumulative energy and watergy alternatives are added to the model. Again, a second order regression line of "best fit" is provided for cumulative alternatives from each region.

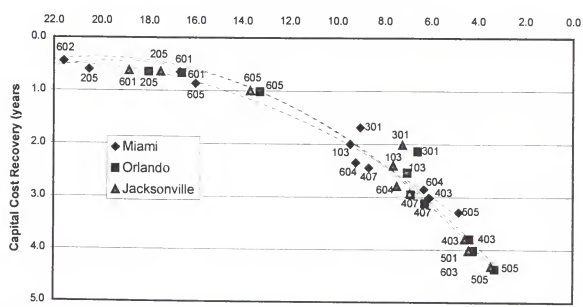

Figure 4.33. Change in payback period and SIR relative to change in DOE projected energy discount rates and capital cost variance for each region, 15 year CCR package.
*Note number codes represent respective energy and watergy alternatives (refer to Tables 4.5– 4.15).

Table 4.20 below shows the cumulative changes in life-cycle SIR and CCR on the bar axis, as well as the cumulative NPV of sustainable energy and watergy alternatives on the tail of the shaded bar. The specific energy and combined water and wastewater rates for each region were used as well as regional capital cost adjustment factors to account for changes in pricing for each area. DOE energy and watergy discount rates from 2000-2025 were also used in the form of a uniform present worth factor. Using the full product life-cycle, a net-present value was then determined for each alternative. Using the cumulative NPV, a cumulative SIR and CCR was calculated.

Table 4.20. Cumulative change in life-cycle SIR, CCR and NPV relative to change in DOE energy discount rates and capital cost variance for each region, 15 year CCR package.

	Sustainable Alternative	Region	SIR ≥2.0 CCR<5.0y	SIR ≥6.0 CCR<4.0y	SIR ≥10.0 CCR<3.0y	SIR ≥14.0 CCR<2.0y	SIR ≥18.0 CCR<1.0y
602	Low-flow shower fixtures	Miami					**$677.54**
		Orlando					**$746.13**
		Jacksonville					**$713.14**
601	Low-flow toilet fixtures	Miami				**$1,306.36**	
		Orlando				**$1,587.49**	
		Jacksonville					**$1,607.12**
205	R-13 batt wall insulation	Miami					**$2,356.36**
		Orlando				**$2,623.99**	
		Jacksonville				**$2,615.94**	
605	Low-flow dishwasher	Miami				**$3,475.46**	
		Orlando			**$3,787.31**		
		Jacksonville			**$3,696.15**		
103	DBL LoE vinyl windows	Miami		**$11,369.26**			
		Orlando		**$11,488.46**			
		Jacksonville		**$11,745.63**			
604	Low-flow clothes washer	Miami		**$11,827.52**			
		Orlando		**$12,019.73**			
		Jacksonville		**$12,279.11**			
301	R-25, 8" ceiling insulation	Miami		**$12,720.31**			
		Orlando		**$12,619.63**			
		Jacksonville		**$13,050.35**			
407	Programmable thermostat	Miami		**$13,002.09**			
		Orlando		**$12,814.37**			
		Jacksonville		**$13,288.11**			
403	8 HSPF/16 SEER ASHP	Miami		**$16,356.80**			
		Orlando	**$15,470.98**				
		Jacksonville	**$15,193.93**				
501	Indoor compact fluorescent	Miami		**$16,576.54**			
		Orlando	**$15,646.99**				
		Jacksonville	**$15,357.12**				
603	Low-flow sink & lavatory	Miami		**$16,638.08**			
		Orlando	**$15,717.19**				
		Jacksonville	**$15,429.56**				
505	Solar DHW	Miami	**$17,867.15**				
		Orlando	**$16,672.74**				
		Jacksonville	**$16,436.50**				

The Green Neighborhood Project: Analyzing Costs of Green Design. The following section compares the results of the life-cycle cost modeling developed herein with a similar research project conducted by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL). The Green Neighborhood/Cool Community Project (GN/CC) was introduced as part of the Model Energy Installation Program (MEIP) to focus integrated environmental and energy savings efforts towards the military family housing sector. Military installations worldwide consisted of 2.4 million people and 1.6 billion square feet of gross floor area in 1993, using some 1.9 billion dollars in energy. Military family housing is somewhat smaller in scale but comparable in construction to that of the civilian sector, comprising 386 million square feet and 3.2×10^9 kWh ($0.4 billion) in annual electricity consumption, roughly 10% of single-family detached housing in high-growth Florida. Using this population, limited scope life-cycle cost models were developed by CERL to assess the capital cost of implementing "green" building technologies.

Results of the CERL study for single-family detached housing at Ft. Hood Texas, a region with similar ambient temperature and economic characteristics as Florida, indicated that the overall cost differential in the physical construction of housing units is approximately 7% higher using green building technologies. Results of life-cycle modeling in high-growth regions of north, central and south Florida indicate that overall turn-key capital costs increase between 3.7% (Miami) to 5.1% (Orlando) for alternatives that each achieve capital cost recovery in 15 years or less, depending on the region. Specifically, double insulated LoE glass increased glazing first costs 110%, compared to a 104% average increase in the high-growth Florida study. Low-flow fixtures added 25% to the cost of conventional plumbing in military housing, compared to 28% increases in high-growth Florida. A 78% and 50% increase was noted for the installation of high efficiency HVAC systems and household appliances, compared to a 67% and 37% increase for similar HVAC and appliance alternatives in high-growth Florida.

The similar capital cost differentials found in both the CERL study and life-cycle cost modeling herein can be attributed to the higher quality materials and systems that will, over the life-cycle of the building, translate directly into resource minimization and an overall savings in energy and watergy costs. Similar to residential development in the private sector, CERL indicated that an inordinate level of importance is placed on first costs and expressed a strong desire for a shift in the prevailing housing paradigm by placing a redirected emphasis on long-range life-cycle planning that would result in maximum eco-economic benefit. Results of Chapter 4 indicate the net present value of future resource savings is between 3.3 and 4.8 times the first cost investment within a 15 year recovery period with CCR occurring within 3.3 and 4.4 years. Communicating these results as well as market survey assessments to industry will be critical in perpetuating this paradigm change.

Conclusions

Although single-family plan-forms vary widely and appreciable climatic differences exist between regions, research has shown that "unitizing" the performance of sustainable alternatives into metrics representing the physical characteristics of the structure and regional climate can produce order-of-magnitude values for resource savings and subsequent ROI per units of HDD/CDD and materials (e.g., MBtu/yr/100ft^2/CDD, kgal/yr/unit). These "average" slide-rule values were proven useful when screening alternatives for more comprehensive performance and ROI modeling. Research also identified a declining marginal utility function that had a significant effect on the performance and subsequent ROI of integrated energy alternatives as the total number of alternatives increased. Adding regional specific resource rates and capital cost structures with resource specific amortization and discounting to integrated energy and watergy "packages" resulted in the derivation of net present values (NPVs) for each alternative. Using the NPV of an alternative with the market MARR data surveyed in Chapter 5, a decision matrix could now be developed to assess the consumers' willingness-to-pay for a given alternative.

Limitations: Geometric differences between plan-forms A and B were eliminated by "unitizing" alternatives into equivalent units of measure. Climatic differences were *partially* accounted for by dividing unit loads and consumption by the number of cooling degree hours (CDH) or heating degree days (HDD) typical for each region. The result of this procedure was a graphic range of values (min/max) and an average value (mean) which could be used to determine the possible range and average energy savings per unit for each alternative based on the number of annual CDHs and HDDs on the building site. The remaining deviation indicates variance which is largely explained by the omission of similar metrics to account for solar orientation and incidence. The NPV of energy and watergy savings presented herein also does not account for lender financing. Since finance rates vary widely depending on inflation, transfer of equity and several other conditions that cannot be generalized to a large research population, these rates were omitted for clarity. However, for LCA on an individual project or owner-occupant level, amortizing the NPV of financing is considered a requirement.

CHAPTER 5
MARKET SURVEY ASSESSMENTS

Introduction

The foundation of this research rests on the assumption that environmentally sustainable residential construction, the first-level dependent variable (DV_1), is primarily influenced by market-consumer response, the first-level independent variable (IV_1). Other factors such as government regulation, financing institutions and insurance underwriters affect the "implementation" of sustainable designs, methods and materials and hence, are considered first-level extraneous variables (EVs_1). The purpose of *Market Survey Assessments* is to conduct a cross-sectional survey with the primary objective of evaluating a second level of causality or dependence, namely the extent to which capital costs and life-cycle return-on-investment (IV_2) affect consumer response (DV_1) to sustainable alternatives. A secondary objective of this study is to assess non-cost related extraneous variables affecting consumer attitudes and perception toward sustainable alternatives. Again, it is assumed that other factors outside of capital costs and life-cycle ROI affect market-consumer response. In order to accurately determine the extent to which capital costs and life-cycle ROI affect consumer response, an attempt must be made to account for these extraneous variables.

Survey Methodology

The methodology of *Market Survey Assessments* can be described in terms of population, instrumentation, data collection, and data analysis. Once a research *population* is defined and an accessible sample population listed, survey *instrumentation* consisting of several questions were developed to assess consumer attitudes toward cost and non-cost related issues pertaining to sustainable residential construction. In light of the complex nature of the survey material, questions were formulated into a reliable and valid survey instrument that was pilot tested prior to *data collection* using telephone interviews. *Data analysis* was then used to describe, correlate and draw inference from the survey response data in an attempt to identify statistically significant relationships and answer research question(s) with an acceptable level of confidence. The metropolitan areas of Jacksonville, Orlando, and Miami representing high-growth regions of north, central and south Florida were used to assess the market elasticity for operationalizing sustainable residential development.

Population

The population of study for this research consists of newly constructed (≥1990) owner-occupied, single family detached housing units (<2,500sf) in high-growth residential regions of north, central and south Florida consisting of the "immediate" metropolitan areas of Jacksonville, Orlando and Miami. For *Life-Cycle Cost Modeling* (Chapter 4), these regions represented the major climatic strata used to determine the cost-benefit range and variance of sustainable energy and watergy alternatives. For *Market Survey Assessments* (Chapter 5), the immediate metropolitan areas of Jacksonville, Orlando and Miami are defined in this study as Duval, Orange, Seminole, Broward, Dade and Palm Beach counties and represent 44% of Florida's 14.5 million population and approximately 50% of its residential owner-occupants. This population was treated as a single aggregate entity. The total number of owner-occupants in this population is 1,592,176. The minimum size of a *simple random sample* from this population with +/- 5% permissible error at a 95% confidence level is 384 (Table 5.1). As a result, the survey utilizes *probability sampling*, since 1) the population is defined, 2) the members of the population are listed, and 3) the random sample ensures each member a known, non-zero chance of being selected.

The sample size for this study was conservatively rounded to 400 and was stratified by the six counties defining the immediate metropolitan areas of Jacksonville, Orlando and Miami. The stratified sample size of owner-occupants in Duval, Orange, Seminole, Broward, Dade and Palm Beach counties were determined by the percentage of owner-occupants in each county relative to the aggregate total (Table 5.4). This survey is intended to be representative of high growth metropolitan areas of north, central and south Florida as defined in this study. Although inferences may be applied to Florida, this survey is not intended to be statistically representative of the State of Florida or any other consituent of the aggregate sample frame.

The procedure for selecting the population was initiated with a database search of parcel numbers of owner-occupied single-family detached housing units constructed during or after 1990 with less than 2,500sf gross floor space. The parcel numbers of residential units meeting this selection criteria in Duval, Orange, Seminole, Broward, Dade and Palm Beach counties were listed and a total of 4,172 parcel numbers randomly selected. Owner-occupant names and addresses were matched to parcel numbers with an estimated 80% minimum success rate resulting in 3,337 entries. Owner-occupant names and addresses were further matched to telephone listings required to conduct the survey with an estimated 40% minimum success rate resulting in no less than 1,335 entries. Finally, the instrument was administered via telephone interview with a conservative 30% minimum success rate resulting in no less than 384 survey completions (Tables 5.2-5.5).

Sample Size. Representativeness and accuracy of the data collected is determined by the *absolute size* and randomness of the sample, rather than by any percentage of the population. The primary sample size criteria is the degree of accuracy desired in the estimation of population values. For *Market Survey Assessments*, a basis must be determined for estimating the deviation of probability sample values from actual population values, or "margin of error." The survey developed to conduct *Market Survey Assessments* implements both item selection and a Likert "type" attitude scale using basic binomial "positive" or "negative" responses. The standard formula for determining sample size for a standard binomial survey with +/-5% margin of error at a 95% confidence interval is,

$$\textbf{Margin of Error} = 1.96\sqrt{(pq)/N}$$

Where,

p = proportion of "positive" responses
q = proportion of "negative" responses
pq = variance of the sample
N = sample size

Standard error is a measure of the accuracy of the sample data as an estimate of the population value. The smaller the standard error, the more likely the sample represents the population. At a 5% margin of error and 95% confidence level, which meets or exceeds publication standards, the interval is the sample value +1.96 standard errors for normally distributed populations (N>50). The sum of p and q must always equal 1.0 (100%) since respondents must either submit a positive or negative response. To find the values of p and q (0.01-0.99) needed to determine the sample size of the survey, a pilot survey can be used. The pilot survey can be avoided however, if the values of of p and q are conservatively set at 0.50 each, since the product of pq is at its maximum when $p = q = 0.50$. The result is the largest possible estimate of the sample size needed (Table 5.1).

$$N = [1.96\sqrt{(pq)}/\text{margin of error}]^2$$
$$N = [1.96\sqrt{(0.5)(0.5)}/0.05]^2$$
$$N = 384.16$$

Table 5.1. Sample sizes for various levels of sampling error, 95% confidence level (54).

Population Size	+/- 5% Error	+/- 4% Error	+/- 3% Error	+/- 2% Error	+/- 1% Error
1,000	278	375	516	706	906
10,000	370	566	964	1,936	4,899
100,000	383	597	1,056	2,345	8,762
500,000	384	600	1,065	2,390	9,423
1,000,000	384	600	1,066	2,395	9,513
2,000,000	384	600	1,067	2,398	9,558

Table 5.2. Sample sizes for various levels of sampling error, 90% confidence level (54).

Population Size	+/- 5% Error	+/- 4% Error	+/- 3% Error	+/- 2% Error	+/- 1% Error
30,000	268	417	733	1,601	5,520
100,000	270	421	746	1,663	6,336
1,000,000	271	423	751	1,688	6,720

Table 5.3. Sample sizes for various levels of sampling error, 99% confidence level (54).

Population Size	+/- 5% Error	+/- 4% Error	+/- 3% Error	+/- 2% Error	+/- 1% Error
30,000	649	1,002	1,737	3,644	10,682
100,000	659	1,026	1,810	3,982	14,229
1,000,000	663	1,036	1,840	4,130	16,319

Table 5.4. Proportional stratified sample size for high-growth residential regions Florida.

County	Population	Occupied Housing	% Owner Occupied	Owner Occupied Housing	% of "High-Growth" Population	Aggregate Sample Size +/-5%, 95%	Stratified Sample Size
Duval	701,673	257,245	62.0%	159,492	10.0%	400	40
Orange	749,631	254,852	59.3%	151,127	9.5%	400	38
Seminole	330,012	107,657	66.9%	72,023	4.5%	400	18
Broward	1,412,165	528,442	68.0%	359,341	22.6%	400	90
Dade	2,031,336	692,355	54.3%	375,949	23.6%	400	95
Palm Beach	972,093	659,588	71.9%	474,244	29.8%	400	119

Table 5.5. Proportional stratified sample procedure for high-growth residential regions of Florida.

County	Random Parcel No. Sample List	Name & Address Generation	Name & Address Sample List	Telephone Number Generation	Telephone Sample List	Telephone Survey Administration	Telephone Survey Completions
Duval	419	x 0.80	335	x 0.40	134	x 0.30	40
Orange	396	x 0.80	317	x 0.40	127	x 0.30	38
Seminole	188	x 0.80	150	x 0.40	60	x 0.30	18
Broward	938	x 0.80	750	x 0.40	300	x 0.30	90
Dade	990	x 0.80	792	x 0.40	317	x 0.30	95
Palm Bch	1,241	x 0.80	993	x 0.40	397	x 0.30	119
TOTALS	**4,172**	**x 0.80**	**3,337**	**x 0.40**	**1,335**	**x 0.30**	**400**

Instrumentation

Type of Survey. *Market Survey Assessments* are intended to provide a cross-section (sample) of a representative portion of high growth residential regions in Florida at a single point in time. The primary research question, *to what extent will capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives*? is a very complex, intangible construct that cannot be answered directly. Since the research question is an opinion and not a tangible or "directly observable" entity, it must be inferred from responses to several interrelated questions correlated toward answering this primary research question.

There are two basic ways in which data are gathered in survey research, interviews and questionnaires. Each of these has two options, thus providing four different approaches to collecting data. While all of the methods utilize a question-asking approach, each has certain advantages and disadvantages to consider before constructing the instrument.

Alternative 1: Mailed Questionnaire. Advantages include guarantee of confidentiality, thus eliciting a more truthful response than personal interviews. Other advantages include good control over sample frame and randomization. Significant disadvantages include the possibility of misinterpretation of the questions by the respondents, especially if subject matter is complex. Another limitation of the mailed questionnaire is a low response rate (<20%). A low response rate limits the generalizability of the results since it cannot be assumed that non-response is randomly distributed across the population (2).

Alternative 2: Directly Administered Questionnaire (captive audience). Advantages include excellent response rate (>70%) and timely, low cost administration. Disadvantages include restriction of when and where the questionnaire can be administered. Significant application limits; usually when sample frame is small, specific and can be assembled in one place at one time (2).

Alternative 3: Personal & Focus Group Interview. Advantages include the opportunity to observe the subject and can provide additional explanation or definition of the question, especially if subject matter is complex. Interviewer can press for more information if response seems to be incomplete. Excellent response rate (>70%). Disadvantages include *interviewer bias* which influence the way questions are asked and subsequently interpreted by the respondent. Another bias introduced through personal contact between interviewer and respondent is the *social desirability bias* which occurs when a respondent provides socially acceptable responses that they would not necessarily give on an anonymous questionnaire. Other significant disadvantages include weaknesses in sample size (N<50) and subsequent representativeness (2).

Alternative 4: Telephone Interview. Advantages include lower cost and faster completion with relatively higher response rates (>30%) than mailed questionnaires. Other advantages include the opportunity to provide additional explanation or definition of the question, especially if subject matter is complex. Respondents have greater feeling of anonymity and hence there may be less interviewer and social desirability bias. Disadvantages include random selection bias associated with availability of telephone and telephone number access (unlisted numbers). Computer systems implementing *random digit dialing* can greatly reduce this source of bias (2).

Alternative 4 was selected as the best survey method for the population to be surveyed and the data to be collected and analyzed. The telephone interview would allow the survey to maintain control over the sample population and reach a representative sample size. Unlike a mail survey, which would generate a 20% response rate or less for subject matter of this complexity, a phone survey may provide a response rate of >30% in a more timely manner.

Types of Questions. Two basic types of questions are used in survey instruments; *closed-ended* or *open-ended*. Open-ended questions allow a free response rather than restricting the respondent to a choice among stated alternatives. Although easier to construct, open-ended questions are very difficult to analyze and their misinterpretation can often be an appreciable source of error. Closed-ended questions are more difficult to construct although easier to tabulate. Since the nature of the research questions are complex and opinion oriented, item selection and Likert type formats were implemented. For most interval scale data, the five-point Likert type scale was used which includes a "neutral" response. For nomial scale demographic questions, such as *age*, and *income*, respondents were given a range of values encompassing all relevant responses.

Validity and Reliability. Validity and reliability are two of the most important considerations in constructing the survey instrument. Of the three tests for validation, including *content*, *criterion*, and *construct* related validity, only content and construct related evidence are applicable for *Market Survey Assessments*. Content-related validity is a type of evidence that shows the extent to which the sample of items on a survey is representative of some defined domain or content. Construct-related validity is a type of evidence that shows a positive correlation or presence of an attitude that is not directly measurable but explains observable effects. Construct-related questions, such as (Question 7 paraphrased) "*I would be willing to spend a little more on conservation features regardless of cost savings, realizing the non-monetary value of many benefits*" must be used to draw inferences to either a negative or positive attitude toward sustainable residential development. The instrument developed for *Market Survey Assessments* was assessed for both content and construct-related validity by the Doctoral Committee and was reassessed following a pilot study by the Florida Survey Research Center (FSRC).

Reliability pertains to the consistency of the survey data. Each observed score has a true-score component and an error-score component. It has been mathematically shown that the variance of the observed scores of a large group of subjects is equal to the variance of true scores plus the variance of errors of measurement. Reliability is therefore theoretically defined as the ratio of the true-score variance to the observed score variance.

The reliability of a survey instrument may also be expressed in terms of the *standard error of measurement* (equation 5.1) which provides an estimate of the range of variation in a set of repeated measurements. By building redundancy into one or more of the survey questions through rephrasing a question without changing its content or interpretation (such as Questions 4-5, 6-7), a set of repeated measurements needed for the standard error of measuement is provided. The standard error of measurement (s_M) is an index of the expected variability of obtained scores around the true score. Given a respondent's obtained score, the s_M can be used to determine the range of scores that will, with a given probability, include the true score. This range is referred to as a *confidence interval*.

Standard Error of Measurement

$$s_M = s_x(\sqrt{1-\alpha})$$

where,

s_M	=	standard error of measurement
s_x	=	standard deviation of test scores
α	=	reliability coefficient, alpha

Equation 5.1. Standard error.

Another widely used measure of consistency that was implemented is *coeffient alpha* (equation 5.2), or *Cronbach alpha* (α). Cronbach alpha is appropriate when measures have items that are expressed as a range of values such as the Likert attititude scale, where value intervals are from 1 to 5 depending on which option was chosen. Since the purpose of this research is to broadly identify significant differences, describe relationships, and draw inferences among variables, the degree of reliability needed in a measure of descriptive-correlational data was established using a coefficient alpha (α) level of 0.10 for the instrument.

Cronbach Alpha $= \alpha = (K/K\text{-}1)[(s_x^2\text{-}\sum s_i^2)/s_x^2)]$

where,

K	=	number of items on survey
$\sum s_i^2$	=	sum of the variances of the item score
s_x^2	=	variance of the survey scores

Equation 5.2. Cronbach alpha.

Once the target population and sampling parameters above were defined, the development of the survey instrument was initiated. The instrument was divided into several "themes" that concentrated on answering the primary and secondary research questions. The University of Florida FSRC assisted in the design of the survey instrument, including question wording, transition between "theme" sections, and measurement of responses. The goal was to design an instrument that addressed the research objectives yet was clear to all respondents so that all respondents understood the meaning of the questions in the same way. As a result, questions of a similar nature were grouped together, starting with the least "invasive" or sensitive topics to place the respondent at ease. Sensitive questions relating to consumer willingness-to-pay to demographics such as income, race and age were intentionally placed last. The survey instrument used for *Market Survey Assessments* begins on next page and includes short narratives explaining the rationale for each respective section.

Time Start _____
Time Ended _____

ID No. ____ ____ ____
Interviewer No. ___ ____
County Code _____

Hello, my name is _____ and I'm calling you from the Florida Survey Research Center at the University of Florida. May I speak with a homeowner who is familiar with appliances and fixtures in the home that affect utility costs? In cooperation with the University of Florida Center for Construction and the Environment we are conducting a survey of homeowners. I assure you that this is not a sales call and that your answers are completely confidential. The survey should only take a few minutes.

1. Overall, how satisfied are you with your current home? Would you say you are...	Very satisfied.....1 Somewhat satisfied.....2 Neither satisfied or not satisfied.....3 Somewhat unsatisfied.....4 Very unsatisfied.....5 Don't know.....8 Refused.....9

The survey summary codes above were provided to ensure that each completed survey was properly classified and that the survey duration, an important indicator of internal consistency, remained as uniform as possible between interviewers. Results showed that survey completion was achieved in an average of 9-12 minutes throughout with little or no deviation between interviewers.

First we would like to ask you some questions about your decision to purchase your home.

2. There are a number of factors that may affect the decision to purchase a home. I will read you a list of factors. Please tell me how important each factor was in your purchase decision. Was it very important, somewhat important, neither important nor unimportant, somewhat unimportant, or very unimportant?

	Very Important	Somewhat Important	Neither Import or Unimpt.	Somewhat Unimportant	Very Unimp.	Don't Know
Security	1	2	3	4	5	8
Appearance	1	2	3	4	5	8
Location	1	2	3	4	5	8
Cost	1	2	3	4	5	8
	(Go to Q 3)			**(Go to Q4)**		

2a. And which of these factors were the most important?

Security.....1
Appearance.....2
Location.....3
Cost.....4

3. There are a number of factors that relate to the cost that may affect the decision to purchase your home. I will read a list of factors. Please tell me how important each factor was in your purchase decision. Was it very important, somewhat important, neither important nor unimportant, somewhat unimportant, or very unimportant?		Very Important	Somewhat Important	Neither Import or Unimpt.	Somewhat Unimportant	Very Unimp.	Don't Know
	Total cost of home	1	2	3	4	5	8
	Interest Rates on Mortgage	1	2	3	4	5	8
	Potential resale value on house	1	2	3	4	5	8
	Monthly mortgage payments	1	2	3	4	5	8
3a. And which of these factors were the most important?	Total cost of home.....1 Interest rates on mortgage.....2 Potential resale value on house.....3 Monthly mortgage payments.....4						

The survey introduction and *Question 1* were developed to provide a "comfortable" opening that would establish a "bond" between the interviewer and respondent and provide another validation that the respondent was actually a member of the target population. If the respondent was not an owner-occupant of a single-family detached "home," the respondent would be inclined to inform the interviewer at this point and terminate the survey. In fact, nearly all of the 8% (125 persons) indicated at this point that they were not members of the target population, even though strict controls were placed on the computerized random survey list generators. *Question 2* was designed to assess the relative importance of several cost and non-cost issues and to determine the extent to which consumer costs might rank with other issues (i.e, security, appearance, location, etc) in the selection of sustainable energy and watergy alternatives. Once cost, the independent variable of study, had been separated from non-cost extraneous variables, the importance of different types of cost structures could be further evaluated. Of particular importance in determining consumer willingness-to-pay for sustainable alternatives are total costs and monthly mortgage payments, which are two of the most common forms of capital costs.

Willingness-to-pay would most likely be influenced by energy and watergy resource savings that would either provide some minimal attractive rate of return (MARR) on a total cost outlay, or, would result in monthly energy and watergy savings at some level greater than the increase in monthly mortgage payments. Subsequently, *Question 3* assessed what types of cost structures (i.e., total cost, interest rates, resale value, monthly mortgage) are most important to consumers, and the extent to which each of these cost structures affect consumer willingness-to-pay by quantifying the weight of each factor in the consumer's decision process. *Questions 4* and *5* were designed to assess awareness of sustainable alternatives and the perception of resource conservation features.

Many homes contain devices or fixtures that can reduce utility costs. I would like to ask you some questions about energy saving devises that may be in your home.

4. Does your home have water saving fixtures such as low flow showers, sink faucets or toilets?	Yes**(GO to 4A)** 1 No**(Go to Q5)** 2 DK**(Go to Q5)** 8
4a. Did the individual who sold you your home inform you that your home had low flow showers, sink faucets or toilets?	Yes **(go to 4b)** 1 No **(Go to Q4d)** 2 DK**(Go to Q4d)** 8
4b. Did this individual describe the savings you would see in utility costs from these items?	Yes 1 No 2 DK 8
4c. How many dollars do you believe that the cost of these fixtures adds to your monthly home mortgage payment? **(Probe: If you had to guess)**	**[ASK EVERYONE 4C and 4D]** _____
4d. How much do you believe that these fixtures reduce the amount of your monthly utility/cost? **(Probe: If you had to guess)**	_____
5. Does your home have high efficiency air conditioning?	Yes**(GO to 5A)** 1 No**(Go to 6)** 2 DK**(Go to Q6)** 8
5a. Did the individual who sold you your home inform you that your home had high efficiency air conditioning?	Yes **(Go to 5b)** 1 No **(Go to 5d)** 2 DK**(Go to Q5d)** 8
5b. Did this individual describe the savings you would see in utility costs from this item?	Yes 1 No 2 DK 8 **[ASK EVERYONE 5C and 5D]**
5c. How many dollars do you believe that the cost of this fixture adds to your monthly home mortgage payment? **(Probe: If you had to guess)**	_____
5d. How much do you believe that this fixture reduces the amount of your monthly utility/cost? **(Probe: If you had to guess)**	_____

6. There are a number of different options that homeowners can use when installing devices to save on utilities. Some of these devices have higher initial costs but save more energy in the long run while others cost less but don't reduce energy costs as much. I am going to read three options regarding energy saving devices that vary in initial cost and yearly savings. Please tell me which you would be most willing to install in your home.

6a. If your home had regular single pane windows that cost a total of $1,200, which of the following options would you consider installing to replace these windows to save energy?

First, single pane, tinted windows that cost	$180	but saves	$40 each year.....1
or single pane, reflective windows that cost	$650	but saves	$95 each year.....2
or double pane, reflective windows that cost	$1,300	but saves	$168 each year.....3
None of these **(Don't read)**	None of these.....4		
Don't know **(Don't read)**	Don't know.....8		

6b. Next, if your home had a basic plumbing package that cost $3500, which of the following options would you consider installing instead to save on utilities?

First, a low flow shower and sink that cost	$80	but saves	$80 each year.....1
or a low flow shower, sink and toilet that cost	$150	but saves	$135 each year.....2
or a low flow shower, sink, toilet and appliances that cost	$400	but saves	$290 each year.....3
None of these **(Don't read)**	None of these.....4		
Don't know **(Don't read)**	Don't know.....8		

6c. Finally, if your home had a basic central air conditioning system that cost $2100, which of the following options would you consider installing instead to save energy?

First, a more efficient air conditioning system that costs	$300	but saves	$130 each year.....1
or a high-efficient air conditioning system that costs	$ 550	but saves	$205 each year.....2
or an ultra-efficient air conditioning system that costs	$1,400	but saves	$305 each year.....3
None of these **(Don't read)**	None of these.....4		
Don't know **(Don't read)**	Don't know.....8		

7. There are a number of new devices that will soon become available that may not reduce your utility cost, but will protect the environment because less electricity will need to be generated. I will list a number of these devices. Please tell me how likely you would be to purchase each of these. First	Very Likely	Somewhat Likely	Neither Likely or Unlikely	Somewhat Unlikely	Very Unlikely	DK
7a. Solar power roof shingles and windows that generate electricity for your home	1	2	3	4	5	8
7b. Natural gas fuel cells that make electricity in your home from natural gas	1	2	3	4	5	8
7c. Ultra-high efficiency heat pumps that both heat and cool your home	1	2	3	4	5	8

Question 6, possibly the single most important question contained within the instrument, was intended to directly measure the extent capital costs and life-cycle ROI affect consumer willingness-to-pay for sustainable energy and watergy alternatives by asking the respondent to choose between three options; a) a low capital cost, low return on investment option, b) a moderate cost, moderate return option, and c) a high cost, high return option. This question format was repeated three times using low, moderate, and high capital cost, high return on investment window, watergy, and HVAC "groups" to a) provide question redundancy, and to b) provide the respondent tangible concepts that could be understood so that inferences to intangible constructs (i.e., research questions) could be accomplished with an appropriate level of reliability and validity. The sustainable window, watergy, and HVAC alternatives and associated cost data used for this survey question were provided by the life-cycle models in Chapter 4. This process was chosen over attempts to answer research questions directly, such as "to what extent to capital costs and life-cycle ROI affect your willingness to pay," or, "what is your minimal attractive rate of return" because considerable error may have been introduced as a result of a) the complexity and misunderstanding of the question, b) and the reliability threat of recording a single response to question that could not be compared to similar questions for consistency.

Inferences to other secondary research questions such as the extent consumers assess a) capital costs, b) capital cost recovery and c) total return in their decision to select sustainable energy and watergy alternatives, can also be achieved using the response data from Question 6 and the life-cycle cost data of Chapter 4, as could the consumer's minimal attractive rate of return (MARR) and margin of affordability. Similarly, *Question 7*, was designed with redundancy and tangible concepts to draw inference to the intangible construct to what extent consumers understand and invest in sustainable energy and watergy alternatives that provide indirect or *soft* cost benefits.

Now just a few more questions for demographic purposes.

8. Sex (Don't ask, just record)	Male.....1 Female.....2
9. What is your age?	_____
10. What is your occupation?	Business owner/manager.....1 Professional (Dr. Lawyer, CEO).....2 Service, Sales, etc.....3 Manufacturing.....4 Secretarial.....5 Students.....6 Retired.....7 Homemaker.....8 Refused.....9
11. Just for statistical purposes, can you tell me if your family's total yearly income before taxes is less than $35,000 or over $35,000? And is that **(READ APPROPRIATE CATEGORY)**	Below $35,000 ref. cat. .....1 Over $35,000 ref. cat. .....2 Under $20,000.....3 $20,000-$34,999.....4 $35,000-$49,999.....5 $50,000-$69,999.....6 $70,000 or more.....7 Refused completely.....8 Don't know.....9
12. And just to make sure we have a representative sample, would you please tell me your race?	Black.....1 White.....2 Asian.....3 Other.....4 Refused.....8
13. And would you say you are of Hispanic ancestry or not?	Yes.....1 No.....2 Don't know.....8 Refused.....9

Demographics were assessed in *Questions 8* through *13* in an effort to cross-tabulate and correlate significant differences in survey question responses to consumer demographics so that a decision matrix could be develop to "match" the ROI patterns of select energy and watergy alternatives specific to consumer's willingness-to-pay according to these demographics (where statistically significant relationships exist, $\rho < 0.10$, $r \geq 0.70$). The demographic characteristics chosen were those considered to have the significant impact on consumer willingness-to-pay for sustainable energy and watergy alternatives, and were largely represented by socioeconomic variables. Because response rates diminish as survey duration is lengthened, survey questions that could answer or draw inference to two or more questions were selected. Education for example, an important socioeconomic variable, could be inferred from occupation, and was therefore not included.

Data Collection

Prior to pilot testing the completed survey draft, the instrument was distributed to the Doctoral Committee and then to the University of Florida Institutional Review Board (UFIRB). The UFIRB reviewed the survey instrument and rendered an approval to conduct the market survey assessment. The criterion required by the UFIRB to "test" human subjects for a survey of this nature consisted of the following:

1. Title of Project
2. Principal Investigator(s)
3. Supervisor (if Principal Investigator is a Student)
4. Dates of the Proposed Project
5. Source of Funding for the Project
6. Scientific Purpose of the Investigation
7. The Scientific Research Methodology
8. Potential Benefits and Anticipated Risk
9. Participant Recruitment (the Number and Age of the Participants, Compensation, etc.)
10. Informed Consent Process

Once UFIRB approval was obtained, the survey instrument was pilot tested using a random sample of approximately 25 respondents from the target sample frame to determine if respondents had any difficulties in answering the questions. The pretest indicated that pilot respondents did not have any problems in completing the survey instrument. Minor cosmetic changes were applied and a final survey instrument was completed.

FSRC personnel began data collection using the random population listing and the finalized survey instrument. All FSRC personnel had extensive survey experience and were further given a "side notes table" and a training session on the subject matter. Supervision was also provided to ensure that the survey instrument was represented in an accurate and consistent manner by the FSRC interviewing staff. Using the telephone as a data collection media, FRSC randomly contacted respondents during weekends, weekday mornings, and weekday evenings to reduce non-response error. A minimum of four (4) "call backs" were given to non-respondents.

Using information only from those who choose to respond can introduce error because the respondents represent an self-selected group that may not represent the views of the entire population. If, after the follow-up procedure presented above resulted in a response rate below 20%, respondents would have been compared demographically to the population in an attempt to determine if respondents are representative of the population in important characteristics such as income, age and occupation. If the respondents had been found to be different from the population, results would have then been limited only to the respondent population. Fortunately, the response rate approached 30% and this procedure was considered unnecessary (Table A-III.16).

Data Analysis

Organizing research data is requisite to statistical analysis. Two methods that were used to organize data from *Market Survey Assessments* include 1) arranging the demographic (nominal scale) and Likert (interval scale) response measures into frequency distributions and 2) presenting the respective nominal and interval data in graphic form. Frequency distributions readily illustrate where data tends to cluster and can easily identify trends and relationships among variables.

Descriptive Analysis. Descriptive statistics for the survey involved frequencies, distributions and percentages as mentioned above as well as measures of central tendency and variability. *Measures of central tendency* provide single indices that represent a set of measures. The most basic of these is the *mode*, or value in a distribution that occurs most frequently. The mode was used to describe frequencies of nominal or "categorical" data sets that have no meaningful numeric value, such as consumer demographics. The most widely used and powerful measure of central tendency for interval data, such as the Likert consumer attitude scale, is the mean. The mean is the sum of all values in a distribution divided by the number of responses. In terms of frequency distributions, the sum of the scores can be computed by multiplying each score by its frequency, summing the products and dividing by the number of total response scores (n).

Although the mean values of two distributions may be identical, the degree of dispersion or *variability* may be significantly different. Measures of central tendency alone therefore, will not provide an accurate picture of the distribution. The simplest of all indices of variability is the *range*, or the difference between the highest and lowest scores in a distribution and is found by subtracting the smallest value from the highest and adding 1. Variance and standard deviation are the most useful measures of variability. By definition, the sum of the deviation scores in a distribution is always 0 since scores above (+) and below (-) the mean balance. To use deviation scores in calculating measures of variability, deviation scores must be squared to produce positive numbers. Variance expressed as the square of the original unit of measure provides proportional relationships. If the original unit of measure is preferred, the square root of the variance, or standard deviation must be used. The z-score is defined as the distance of a score from the mean measured by standard deviation units. The z-score may be used to make comparisons of consumers with different attitude score means and standard deviations.

Correlational Analysis. As one of the most important components of statistical analysis for *Market Survey Assessments*, correlational procedures were used to determine the extent to which a change in one variable is associated with change in another variable for the purposes of 1) prediction, 2) instrument consistency (reliability), and 3) describing relationships. Statistical indices have been developed that indicate both the direction and the strength of a relationship between variables. A *correlation coefficient* of –1.00 indicates a perfect negative relationship, a value of +1.00 indicates a perfect positive correlation, and the a value of 0 indicates no relationship. A perfect positive correlation results when the item response *z-score* on one variable is identical in size and sign to the *z-score* on the other variable. A perfect negative correlation results when the item response *z-score* on one variable is identical in size but opposite in sign. A correlation coefficient near unity, either – 1.00 or +1.00, indicates a high degree of relationship. The intent of *Market Survey Assessments* is to collect cost and non-cost preference data on owner-occupants in single-family detached housing in high-growth regions of north, central and south Florida. Data reflecting cost-benefit attitudes of these "consumers" on specific sustainability issues may be correlated to broader concepts, namely the extent to which capital and life-cycle costs affect consumer willingness to pay for sustainable alternatives. In this case, correlation coefficients may allow accurate predictions of the "willingness-to-pay" variable on the basis of information about other variables such as consumer demographics.

Pearson r (equation 5.3), or the product moment coefficient of correlation, is the most commonly used correlation index for interval and ratio data and is defined as the mean of *z-score* products (item response *z-score* for variable *X* multiplied by *z-score* on variable *Y*). These paired z-score products are added and the sum is divided by the number of pairs. The product moment coefficient of correlation belongs to the same statistical family as the mean. Its computation takes into account the size of each score in both distributions, X and Y. Correlative relationships may either be linear or curvilinear. If the relationship among variables is curvilinear, a Pearson *r* will underestimate the strength of the relationship. To avoid this problem, a scattergram of the data for Market Survey Assessments was also organized and examined.

Pearson *r* Correlation Coefficient $= \Sigma z_x z_y / N$

$$r = \frac{\Sigma XY - (\Sigma X)(\Sigma Y)/N}{\{[\Sigma X^2 - (\Sigma X)^2/N][\Sigma Y^2 - (\Sigma Y)^2/N]\}^{1/2}}$$

where,

r	=	the Pearson coefficient of correlation
$\Sigma z_x z_y$	=	the sum of the z-score products
ΣX	=	the sum of scores in *X*-distribution
ΣY	=	the sum of scores in *Y*-distribution
ΣXY	=	the sum products of paired *X* and *Y*-scores
ΣX^2	=	the sum of squared scores in *X*-distribution
ΣY^2	=	the sum of squared scores in *Y*-distribution
N	=	the number of paired scores (responses)

Equation 5.3. Pearson *r* correlation coefficient.

In order to provide accurate interpretations of correlational indices, a criteria defining the strength of "meaningful" relationships among variables must be established. Quantitative measures for determining the correlation among variables must also be placed into context. An r value of 0.60 (Table 5.6) would be considered low for the relationship between mean owner-occupant income and affordability, but high for the relationship between level of education and average duration between relocation. The later scenario is assumed to be affected by a greater number of extraneous variables than the first and hence, the variability caused by level of education is less. An index for assessing the relative strength of a relationship that does not involve arbitrary categories (as does correlation coefficient, "r" above) is the *coefficient of determination* (r^2). This square of the correlation coefficient indicates the proportion of variance that a given set of variables have in common. If the r between marginal rate of return (MARR) and age is 0.50 for instance, then the proportion of variance is $r^2 = (0.50)^2 = 0.25$, meaning that 75% of the variance in MARR is accounted for by factors other than age.

Table 5.6. Pearson r values.

Value of "r"	Relationship
0.86-1.00	Very high
0.70-0.85	High
0.50-0.69	Moderate
0.20-0.49	Low
0.00-0.19	Negligible

For *Market Survey Assessments*, many cost, non-cost, and demographic variables are assumed to affect the consumers' attitude toward sustainable residential construction. To establish a trend of how a given demographic variable will affect an owner-occupant's willingness-to-pay for sustainable alternatives, a regression line is used. Specifically, a *second order polynomial regression* (equation 5.4) calculates the "least squares" fit through given data points. This statistical procedure weights each predictor so that the predictor variables in combination provide the optimal prediction of the criterion (Y'). To determine which predictors should be used, the first predictor variable considered for entry will be the one with the largest positive or negative correlation with the criterion. A variable enters into the regression only if the probability associated with an *Chi-Square* (x^2) *test of significance* is ρ less than or equal to 0.10. Once a combination of significant predictors has been found, a *multiple correlation* (R) and a *multiple coefficient of determination* (R^2) must assess the cumulative correlation "weight" of the predictors and the value of the constant, which is equal to the variance not accounted for by the predictor variables. The *standard error of the estimate* can then be determined to provide a range of values that the predicted criterion is likely to fall with a given probability or *confidence interval* (σ = 68%, 2σ = 95%).

2nd Order Polynomial Regression

$$Y' = b + c_1x + c_2x^2$$

where,

Y' = the criterion to be predicted
b = constant
$c_1 \ldots c_n$ = regression weight for each predictor
x = score on each predictor

Equation 5.4. Non-linear regression

Inferential Analysis. Statistical inference is an imperfect inductive process where one estimates *parameters* (characteristics of populations) from *statistics* (characteristics of samples). Different from descriptive analysis, such inferences are based on the laws of probability and are based on estimations rather than absolute facts. Inferential analyses are a critical element of *Market Survey Assessments*, addressing the research questions on the basis of observations of a sample drawn from the population with a certain degree of error.

When an inference is made from a sample to a population, a certain amount of error is involved because even samples that are random can be expected to vary from one to another (2). *Sampling error* is the difference between a population parameter and a sample statistic. Since the population parameters of owner-occupants living in newly constructed (≥1990), single family detached housing units (<2,500sf) in high-growth residential regions of north, central and south Florida are unkown, the variability of samples can be estimated using inferential statistics. It has been stated that sampling error manifests itself in the variability of sample means (2). Thus, the standard deviation of a collection of means from random samples taken from a single population provides an estimate of the magnitude of sampling error. Once both variables affecting sampling error are known, namely the size and standard deviation of the population, the *standard error of the mean* (equation 5.5) can be determined.

Standard Error of Mean $= \sigma_{\bar{x}} = \sigma/\sqrt{n}$

where,

$\sigma_{\bar{x}}$	=	the standard error of the mean
σ	=	the standard deviation of the population
n	=	number in each sample

Equation 5.5. Error of the mean.

Type I and Type II errors are associated with accepting or rejecting a null hypothesis (H_o). Type I error is evident when a relationship is perceived to exist when there is none. Type II error, the opposite, exists when a significant relationship is dismissed. Although the research design of *Operationalizing Sustainable Residential Development* involves inferences of consumer attitudes toward willingness-to-pay for sustainable alternatives through research questions (and not null hypotheses), Type I and Type II errors were still controlled by establishing an accepted *level of significance*. The predetermined level at which inferences can be drawn toward answering research questions, such as "the extent to which capital and life-cycle costs affect consumer willingness-to-pay" is called level of significance. Since excessive control of Type I error compromises control of Type II error and visa versa, and that neither Type I or Type II errors are considered more important than the other, a "modest" $\rho < 0.10$ level of significance, an industry norm, was used. A $\rho < 0.10$ significance level indicates inferences toward answering a research question were accepted if the estimated probability of the observed relationship being a chance occurrence is less than 1 in 10.

Crosstabulations were used to show how frequently various combinations of nominal demographic variables occur, and identify subsequent trends or relationships between owner-occupant characteristics and consumer attitudes toward sustainable residential construction. To find the statistical significance of differences among the proportions and percentages of nominal data, the *chi-square* (X^2) test was used (equation 5.6). In the chi-square test, two sets of frequencies are compared; *observed frequencies* and *expected frequencies*. Observed frequencies (f_o) as the name implies, are the actual frequencies obtained by observation. Expected frequencies (f_e) are theoretical frequencies, which are used for comparison. To determine whether a chi-square value is significant, the *degrees of freedom* (*df*) must be established. The *df* value is based on the number of observations that are free to vary once certain restrictions are placed on the data. The *df* value equals $K - 1$, where K is the number of categories used for classification (Table 5.7).

$$\text{Chi Square} = X^2 = \Sigma[(f_o - f_e)^2 / f_e]$$

where,

X^2 = the value of the chi-square
f_o = the observed frequency
f_e = the expected frequency

Equation 5.6. Chi-square significance.

Table 5.7. Chi-square values of significance for select degrees of freedom (2).

df	0.99	0.80	0.50	0.30	0.10	0.05	0.02	0.01	0.001
1	0.000	0.642	0.455	1.074	2.706	3.841	5.412	6.635	10.827
2	0.201	0.446	1.386	2.408	4.605	5.991	7.824	9.210	13.815
3	0.115	1.005	2.366	3.665	6.251	7.815	9.837	11.345	16.266
4	0.297	1.649	3.357	4.878	7.779	9.488	11.668	13.277	18.467
5	0.554	2.343	4.351	6.064	9.236	11.070	13.388	15.086	20.515
10	2.558	6.179	9.342	11.781	15.987	18.307	21.161	23.209	29.588
15	5.229	10.307	14.339	17.332	22.307	24.996	28.259	30.578	37.697
20	8.260	14.578	19.337	22.775	28.412	31.410	35.020	37.566	43.315
30	14.953	20.599	29.336	33.530	40.256	43.773	47.962	50.892	59.703

Chi-square however, will only indicate whether nominal demographic variables are related or independent, not the extent to which variables are related. In order to determine the extent of the relationship between two variables, a coefficient of correlation must be calculated. A coefficient frequently used for nominal data is the *phi coefficient* (ϕ). The phi coefficient is a mathematical simplification of the *Pearson product moment coefficient* for nominal crosstabs. Hence, phi has a value of 0 when no correlation exists between variables, +1.00 when a perfect positive correlation exists, and –1.00 when a perfect negative correlation exists. For larger, more complex nominal data sets (>2 variables), an appropriate measure of correlation is the *Kappa statistic* (κ). If there exists a perfect correlation between variables, κ will equal 1.00. If agreement between variables is exactly what would be expected through chance, κ equals 0. If agreement is less than would be expected by chance, κ will be a negative number (2).

Survey Results

Once the data were collected, *Market Survey Assessment* results were analyzed for the statistical parameters listed in Table 5.8 using Microsoft EXCEL 97® with the intent of drawing statistical inferences toward answering the research questions below. Supplemental data collected during market survey assessments may also be found in Appendix III.

Table 5.8. Summary of descriptive, correlational and inferential analyses implemented (2).

Scale of Variables	Description	Central Tendency	Variability	Correlation	Inference Significance
Interval Data (numerical assignment, equal intervals)	Frequencies and Percentages	Mean Standard error of the mean	Standard deviation, variance	Pearson *r* Regression Analysis	Chi-Square χ^2
Nominal Data (qualitative categorization)	Frequencies and Percentages	Mode	Range	Cross-tabulation	

Primary Research Question(s)

1. To what extent will capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives?

Secondary Research Question(s)

2. To what extent will consumer cost rank with other issues (i.e., security, appearance, location) in the selection of sustainable energy and watergy alternatives?

3. What types of cost structures (i.e., total cost, interest rates, resale value, monthly mortgage) are most important to consumers?

4. To what extent do consumers assess a) margin of affordability (maximum capital cost investment), b) minimal attractive rate of return (savings-to-investment ratio, capital cost recovery period), and c) maximum return-on-investment in their decision to select sustainable energy and watergy alternatives?

5. To what extent will consumers understand and invest in sustainable energy and watergy alternatives that provide indirect or "soft" cost benefits (i.e., protection of the environment)?

1. **To what extent will capital costs and life-cycle return on investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives?**

To assess the relationship between capital costs and life-cycle ROI, respondents were asked to choose between low, moderate and high capital cost, high return alternatives. Data showed that consumers were most "willing-to-pay" for high cost, high return alternatives (42%) compared to moderate (25%) or low capital cost, low return (22%) alternatives (Figure 5.1). The range of capital costs and ROI_{max} for low, moderate and high cost, high return window, watergy and HVAC alternatives was \$80-\$300, \$720-1,650; \$150-\$550, \$1,200-\$2,520; and \$400-1,400, \$2,495-3,745 respectively.

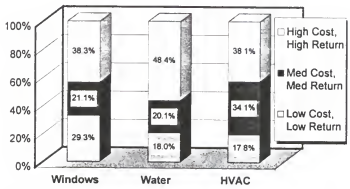

Figure 5.1. Distribution of consumer willingness-to-pay for low, moderate and high cost, high return sustainable window, watergy and HVAC alternatives.

Window, watergy and HVAC alternatives were intended to provide the respondent "tangible" alternatives they could relate to yet *equally* measure their consideration of capital costs and life-cycle ROI in willingness-to-pay. The 2nd-order regression below shows the correlation among respective L (low), M (moderate) and H (high) window, watergy and HVAC alternatives was high while differences between low, moderate and high cost, high return alternatives were significant. The percentage of willingness-to-pay as shown on the y-axis of Figure 5.2, is defined as the number of respondents selecting a given alternative over other sustainable alternatives provided, and is *not* the typical definition, willingness-to-pay for a sustainable alternative over a conventional alternative.

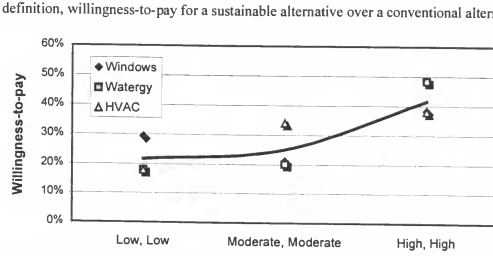

Figure 5.2. Trend analysis of consumer willingness-to-pay for low, moderate and high cost, high return sustainable window, watergy and HVAC alternatives. Differences between low, moderate and high cost, high return groups "significant" ($\rho < 0.01, 0.03, 0.01$). Correlation among window, watergy, and HVAC groups "high" ($r = 0.70\text{-}0.85$).

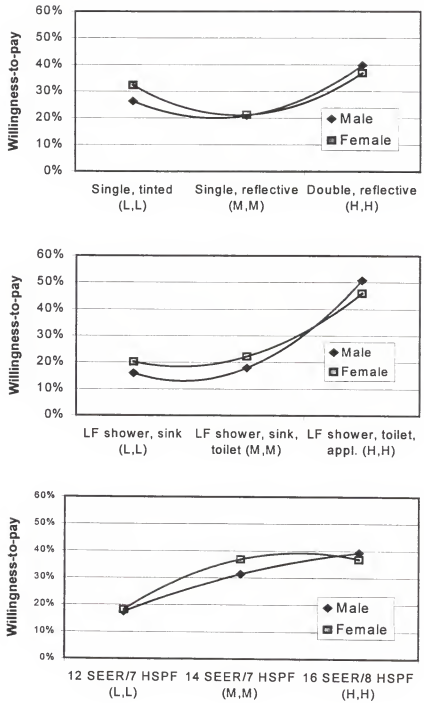

Figure 5.3. Trend analysis comparing *gender* to consumer willingness-to-pay for low, moderate and high cost, high return on investment window, watergy and HVAC alternatives.

Once aggregate willingness-to-pay averages had been determined from the population as a whole, crosstabulations were used to determine if significant differences existed between population and individual consumer demographics. If significant differences were found to exist among specific demographic groups, then the *Decision Analysis Matrix* developed in Chapter 6 would account for these differences in order to more accurately match the ROI patterns of sustainable alternatives to specific consumer willingness-to-pay profiles.

The first of these demographic analysis suggested that *gender* had little influence on the consumer's choice between low, moderate and high capital cost, high return alternatives. As the trend analysis in Figure 5.3 shows, male and female respondents selected sustainable window, watergy and HVAC alternatives similarly. Aggregate gender averages were consistent with aggregate population averages as shown in Figure 5.1. However, consumer response to low, moderate and high cost, high return window and watergy alternatives showed nearly identical trends whereas response to HVAC alternatives showed a significantly greater willingness-to-pay for moderate alternatives than moderate alternatives in either window or watergy groups, indicating the possible emergence of an affordability "ceiling" for added capital cost, regardless of future returns. The added capital cost increase of low (12 SEER), moderate (14 SEER) and high cost, high return (16+ SEER) HVAC alternatives is $300, $550, and $1,400. The life-cycle ROI of low, moderate and high cost, high return HVAC alternatives is $1,650, $2,520, and $3,175 respectively. Even though the SEER 16 alternative achieved a greater total return over its useful life, respondents were nearly as likely to select the moderate 14 SEER alternative due to either its lower capital cost or faster capital cost recovery. Again however, the differences between gender as well as race were statistically insignificant and largely reflective of overall population totals. Tables 5.9-5.10 and Figures 5.4-5.5 show the sum distribution of consumer response to low (L,L), moderate (M,M) and high cost, high return (H,H) window, watergy and HVAC alternatives categorized by gender and race respectively.

Table 5.9. *Gender* distribution of willingness-to-pay for low, moderate and high cost, high return sustainable alternatives.

Gender	L,L	M,M	H,H
Male	20%	24%	43%
Female	24%	27%	43%

Table 5.10. *Race* distribution of willingness-to-pay for low, moderate and high cost, high return sustainable alternatives.

Race	L,L	M,M	H,H
Black	26%	23%	42%
White	22%	27%	40%

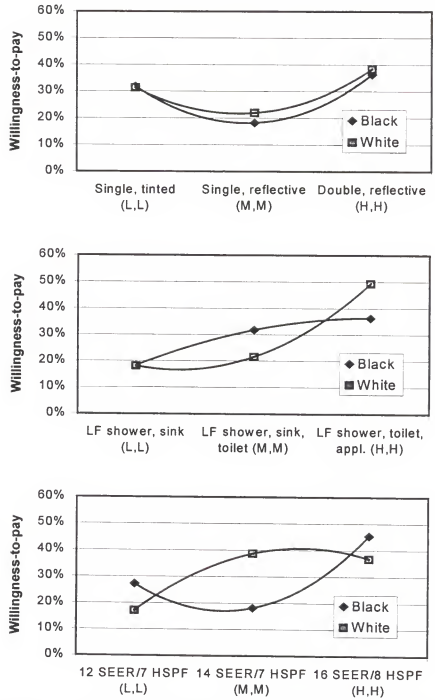

Figure 5.4. Trend analysis comparing *race* to consumer willingness-to-pay for low, moderate and high cost, high return on investment window, watergy and HVAC alternatives.

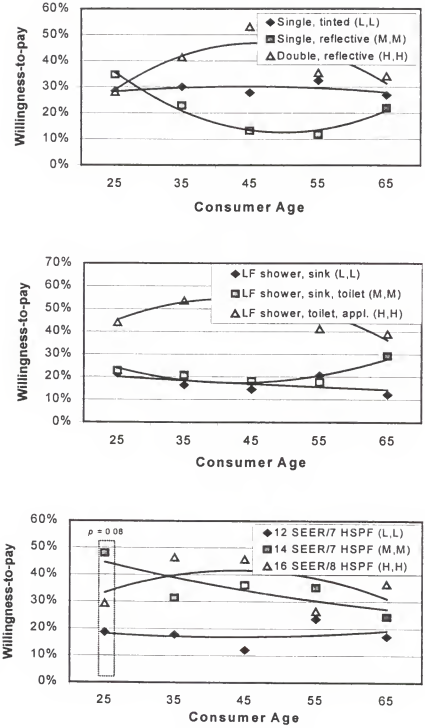

Figure 5.5. Trend analysis comparing *age* to consumer willingness-to-pay for low, moderate and high cost, high return on investment window, watergy and HVAC alternatives.

Analysis of consumer age revealed that willingness-to-pay for high cost, high return alternatives increased from as low as 33% to as high as 52% as consumers approached middle age (35-45) and steadily decreased thereafter to 37% by age 65 (Table 5.11). Consumer interest in low cost, low return window, watergy and HVAC alternatives remained relatively unchanged between age groups, averaging between 20% and 30%. Willingness-to-pay for moderate cost alternatives was found to be inversely proportional to high cost, high return alternatives. For all age groups however, interest in high cost, high return alternatives remained distinctly above both low and moderate cost, moderate return alternatives, except for consumers 25-35 years of age. This age group demonstrated a significant willingness-to-pay for moderate alternatives over high cost, high return alternatives (HVAC, $\rho = 0.08$).

Table 5.11. *Age* distribution of willingness-to-pay for low, moderate and high cost, high return sustainable alternatives.

Age	L,L	M,M	H,H
25-34	32%	35%	33%
35-44	22%	25%	47%
45-54	18%	22%	52%
55-64	25%	21%	34%
65+	19%	25%	37%

Analysis of consumer occupation (Table 5.12) indicates that all occupations were generally reflective of the population, choosing first high cost, high return alternatives followed by moderate and low cost, low return alternatives in descending order. "Homemakers" however, were found to have statistically significant differences, preferring low cost, low return alternatives to moderate and high cost alternatives. An analysis of income (Table 5.13, Figure 5.6) revealed no statistically significant differences between levels of economic means, although consumer willingness-to-pay gradually favored high cost, high return window, watergy and HVAC alternatives as income increased.

Table 5.12. *Occupation* distribution of willingness-to-pay for low, moderate and high cost, high return sustainable alternatives.

Occupation	L,L	M,M	H,H
Professional	26%	20%	45%
Service	20%	27%	44%
Admin	28%	28%	43%
Retired	20%	23%	38%
Homemaker	35%	28%	26%

Table 5.13. *Income* distribution of willingness-to-pay for low, moderate and high cost, high return sustainable alternatives.

Income	L,L	M,M	H,H
<$20K	29%	14%	25%
$20K-$34K	22%	27%	28%
$35K-$49K	22%	26%	40%
$50K-$64K	15%	28%	48%
$65K+	16%	27%	53%

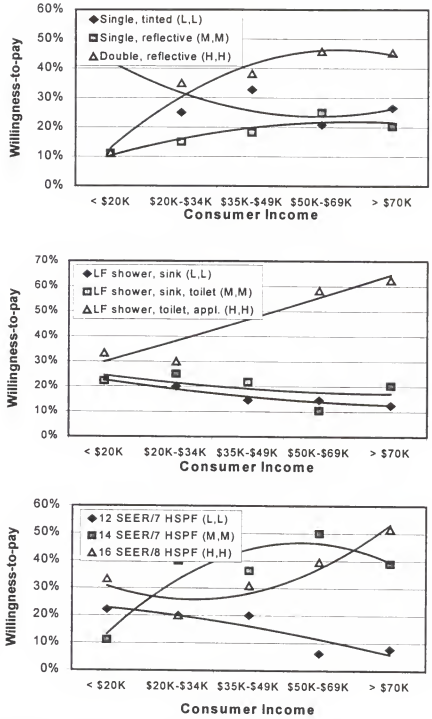

Figure 5.6. Trend analysis comparing *income* to consumer willingness-to-pay for low, moderate and high cost, high return on investment window, watergy and HVAC alternatives.

2. To what extent will consumer cost rank with other issues (i.e., security, appearance, location) in the selection of sustainable energy and watergy alternatives?

The fundamental hypothesis supporting this research is that sustainable residential development should be governed by the economic system, and that the economic system should be as reflective as possible of the natural system, providing a life-cycle "payback" for reduced resource consumption and subsequent environmental degradation. Yet, in order to create this "market-based" paradigm where sustainable alternatives provide economic rewards and unsustainable alternatives carry economic penalties, costs must first be viewed as the primary force in the decision process of the consumer. To operationalize sustainable residential development by stimulating a market interest in the cost-benefit of sustainable building alternatives, the extent consumers will rank costs with non-cost issues in their decision making process must first be assessed.

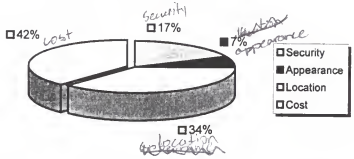

Figure 5.7. Frequency distribution of consumer cost rank with non-cost related willingness-to-pay variables.

As shown in Figure 5.7 above, "costs" are clearly the most important variable in the decision making process of the consumer, carrying 42% of the overall decision weight compared to 34%, 17% and 7% for appearance, security and location respectively. Consequently, a potential exists for the consumer acceptance and market integration of sustainable energy and watergy alternatives that provide a positive return-on-investment through the payback of resources conserved.

Further analysis suggests that the willingness-to-pay decisions of certain demographic groups are affected by costs in different ways. Although costs remain the leading criteria for selecting sustainable alternatives over conventional alternatives, the extent that consumer costs rank with other issues varies mostly by consumer age and income. Consumers age 25-34 actually chose location over cost as a leading criteria ($\rho = 0.07$). Conversely, consumers age 45-54 were more than twice as likely to select cost as a primary willingness-to-pay variable than all non-cost related variables combined ($\rho = 0.05$), as did consumers with income levels of \$20K-\$34K ($\rho = 0.04$) as shown in Figure 5.9 on the following page.

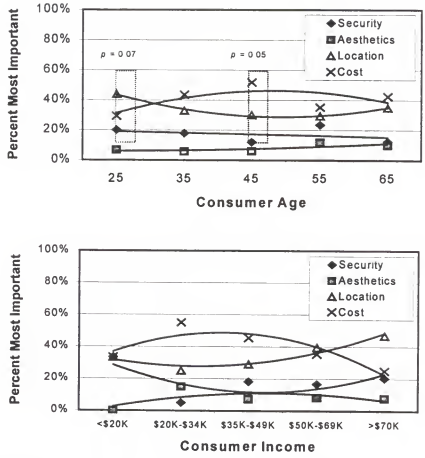

Figure 5.8. Trend analysis comparing *age* and *income* to consumer ranking of cost and non-cost issues. Significant differences between observed and expected values from 25-35 (ρ = 0.07) and 45-55 (ρ = 0.05) age groups. Significant differences between observed and expected values from \$20K-\$34K (ρ = 0.04) income groups.

3. What types of cost structures (i.e., total cost, interest rates, resale value, monthly mortgage) are most important to consumers?

Once cost, the independent variable of study, had been separated from non-cost extraneous variables, the importance of different types of cost structures could be further evaluated. Again, willingness-to-pay would most likely be influenced by energy and watergy resource savings that would provide some minimal attractive rate of return, justifying an added capital cost investment. Of particular concern are total costs and monthly costs, two of the most common forms of capital investment and resource (utility) consumption cost structures. As shown in Figure 5.9, total and monthly costs were most important to consumers (34% and 27% respectively).

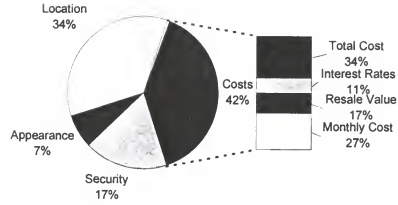

Figure 5.9. Frequency distribution of consumer cost rank by type of cost structure.

Results from Figure 5.10 clearly indicate that monthly costs are most important to younger, working consumers age 25-54, whereas total costs are of significantly greater importance to consumers age 65+ ($\rho = 0.06$) and the closely related retired ($\rho = 0.02$).

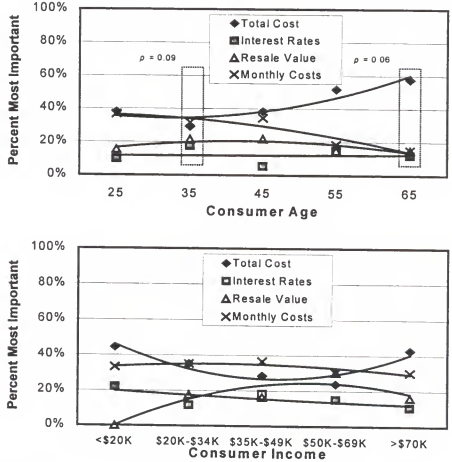

Figure 5.10. Trend analysis comparing *age* and *income* to consumer ranking of type of cost structure. Significant differences between observed and expected values from 35-45 ($\rho = 0.09$) and 65+ ($\rho = 0.06$) age groups.

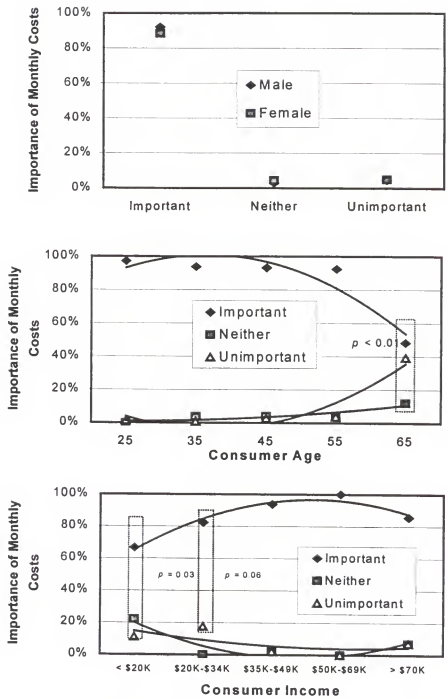

Figure 5.11. Trend analysis comparing *gender, age* and *income* to surveyed level of "importance" of monthly costs. Significant differences between observed and expected values from 65+ ($\rho < 0.01$) age groups. Significant differences between observed and expected values from <$20K ($\rho = 0.03$) and $20K-34K ($\rho = 0.06$) income groups.

4. **To what extent do consumers assess a) margin of affordability (maximum capital cost investment), b) minimal attractive rate of return (savings-to-investment ratio, capital cost recovery period), and c) maximum return on investment in their decision to select sustainable energy and watergy alternatives?**

Data suggests that costs are the single greatest factor in the consumer's willingness-to-pay decision for sustainable alternatives, and given a choice, consumers were generally inclined to select high cost, high return-on-investment alternatives. However, the moderate cost, moderate return HVAC alternative (34.1%) approached and, in some demographic sub-groups, exceeded willingness-to-pay for the high cost, high return HVAC alternative, indicating the emergence of a possible affordability "ceiling" since the capital cost of the high cost, high return HVAC alternative was greater than that of any other alternative. Factors such as margin of affordability (MOA), minimal attractive rate of return (MARR), and maximum return on investment (ROI_{max}), were predicted to account for some variance in consumer willingness-to-pay. Yet, further analysis was needed to determine the effects, if any, of these underlying ROI cost structures on the consumer's decision to select sustainable energy and watergy alternatives.

Margin of Affordability. As the maximum investment that can be afforded by the consumer for a given return, margin of affordability is simply the willingness-to-pay for an increase in capital costs. To determine the margin of affordability, the changes in willingness-to-pay were evaluated as a function of changes in capital costs. Surprisingly, willingness-to-pay was positively correlated to increase in capital costs, meaning willingness-to-pay increased as capital costs increased ($r = 0.90$). The consumer's willingness-to-pay for higher capital cost likely stems from corresponding increases in total returns over the product life-cycle. Yet further analysis suggests that the "ratio" of changes in capital costs between alternatives do affect willingness-to-pay. Using data from Table 5.14, Figure 5.12 plots the change in willingness-to-pay in relation to the *ratio* change in capital costs.

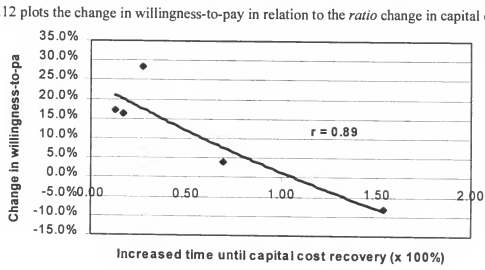

Figure 5.12. Percent change in willingness-to-pay relative to ratio change in capital cost increase.

To determine the "ratio" change in willingness-to-pay relative to a change in capital costs, the capital cost increase between low and moderate cost, moderate return alternatives were compared to the difference between that of moderate and high cost, high return window, watergy and HVAC alternatives. As shown in Table 5.14 for example, the difference in capital cost increase of a single-pane LoE window is $470.00, or a factor of 2.61x greater than the cost of a single-pane tinted window, corresponding to a 8.2% reduction in willingness-to-pay. The difference in capital cost increase of a double-pane LoE window is $650.00, or a factor of only 1.00x greater than the cost of a single-pane LoE window, corresponding to a 17.2% *increase* in willingness-to-pay. This simple analysis indicates that the ratio of increased capital cost is a more significant affordability index (r = 0.96) than the actual dollar change in cost (r = 0.45).

Table 5.14. Comparison of low, moderate and high cost, high return, window watergy and HVAC alternatives using straight-line analysis over the product service-life (windows, 30 year; watergy, 10 year; HVAC, 15 year).

	Low Cost, Low Return	Δ Low-Moderate		Moderate Cost, Moderate Return	Δ Moderate-High		High Cost, High Return
Windows	*Single, tint*			*Single, LoE*			*Double, LoE*
Willingness-to-pay	**29.3%**	**-8.2%**	**-0.28**	**21.1%**	**17.2%**	**0.82**	**38.3%**
ΔCC	$180	$470	2.61	$650	$650	1.00	$1,300
ROI_{annual}	$40	$55	1.38	$95	$73	0.77	$168
ROI_{annual} : ΔCC	0.25:1.0	-0.10	-0.40	0.15:1.0	0.00	0.00	0.15:1.0
CCR	4.5 yrs	2.3 yrs	1.54	6.8 yrs	0.9 yrs	0.13	7.7 yrs
ROI_{max}	$1,020	$1,180	1.16	$2,200	$1,550	0.71	$3,750
SIR	5.6:1.0	-1.7	-0.30	3.9:1.0	-1.0	-0.26	2.9:1.0
Watergy	*Sink & shower*			*Sink & toilet*			*Fixtures & appl.*
Willingness-to-pay	**18.0%**	**2.1%**	**0.18**	**20.1%**	**28.4%**	**1.41**	**48.4%**
ΔCC	$80	$70	0.88	$150	$250	0.67	$400
ROI_{annual}	$80	$55	0.69	$135	$155	1.15	$290
ROI_{annual} : ΔCC	1.0:1.0	-0.10	0.10	0.90:1.0	-0.15	0.17	0.75:1.0
CCR	1.0 yrs	0.1 yrs	0.10	1.1 yrs	0.3 yrs	0.27	1.4 yrs
ROI_{max}	$720	$480	0.66	$1,200	$1,295	1.08	$2,495
SIR	9.0:1.0	-1.0	-0.11	8.0:1.0	-1.8	-0.23	6.2:1.0
HVAC	*12 SEER*			*14 SEER*			*16+ SEER*
Willingness-to-pay	**17.8%**	**16.3%**	**0.92**	**34.1%**	**4.0%**	**0.12**	**38.1%**
ΔCC	$300	$250	0.83	$550	$850	1.55	$1,400
ROI_{annual}	$130	$75	0.58	$205	$100	0.49	$305
ROI_{annual} : ΔCC	0.40:1.0	0.00	0.00	0.40:1.0	0.20	0.50	0.20:1.0
CCR	2.3 yrs	0.4 yrs	0.17	2.7 yrs	1.9 yrs	0.70	4.6 yrs
ROI_{max}	$1,650	$870	0.53	$2,520	$650	0.26	$3,170
SIR	5.5:1.0	-0.9	-0.16	4.6:1.0	-2.3	-0.50	2.3:1.0

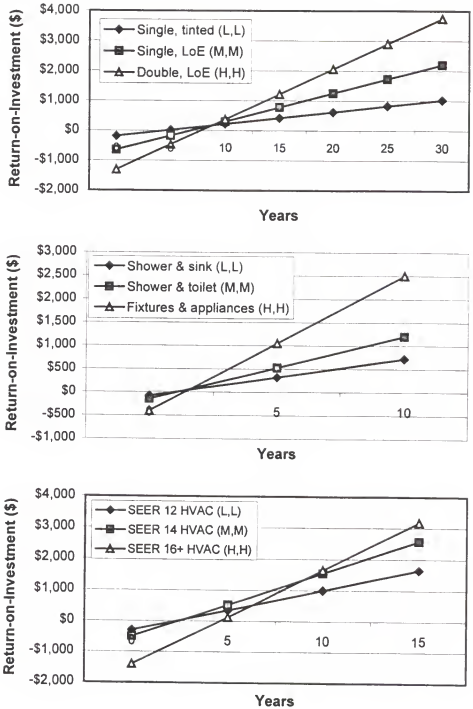

Figure 5.13. Comparison of low, moderate and high cost, high return, window watergy and HVAC alternatives using straight-line analysis over the product service life (x-axis represents 1995 MEC baseline).

Minimal Attractive Rate of Return (MARR). Although expressed in many forms, MARR can be as a desired period of capital cost recovery. As shown in Figure 5.14, capital cost recovery is the second and from a statistical vantage point, the most significant MARR variable affecting consumer willingness-to-pay. Similar to capital costs, willingness-to-pay was positively correlated to increase in capital cost recovery, meaning willingness-to-pay increased as the time necessary to recover the capital cost investment increased (r = 0.79). The consumer's willingness-to-pay for extended recovery periods most likely results from corresponding increases in total returns over the product life-cycle. Again however, further analysis suggests that the magnitude of marginal changes in capital cost recovery between alternatives do affect willingness-to-pay.

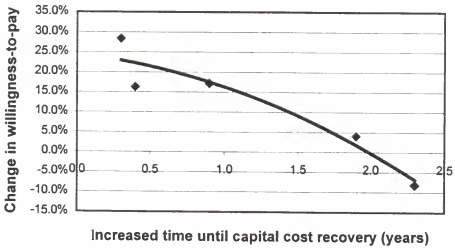

Figure 5.14. Change in willingness-to-pay relative to marginal change capital cost recovery.

Total Return-on-Investment. Although the ratio and marginal differences in capital cost and capital cost recovery between "low-moderate" and "moderate-high" window, watergy and HVAC alternatives *may* have underlying influences on willingness-to-pay, maximum return-on-investment over the product life-cycle was found to be the most influential independent variable. Results find that willingness-to-pay for each alternative is positively correlated to the actual dollar amount of maximum return-on-investment (r = 0.90).

5. To what extent will consumers understand and invest in sustainable energy and watergy alternatives that provide indirect or "soft" cost benefits (e.g., protection of the environment)?

The fundamental objective of this research is to determine the viability of sustainable residential development through market-based economic structures, meaning reduced energy and watergy resource consumption and subsequent reduced environmental impact should become a competitive advantage over inefficient use of resources. However, many adverse effects of inefficient resource use will continue to be *externalized*, or left unaccounted for in market-based decision processes for the foreseeable future. The effects that "hard" capital and life-cycle costs have on willingness-to-pay have been surveyed and extensively analyzed in research questions 1-4. It is now necessary to assess the consumer's willingness-to-pay for "soft" cost benefits, or societal benefits that are derived from reducing negative, externalized effects of resource exploitation.

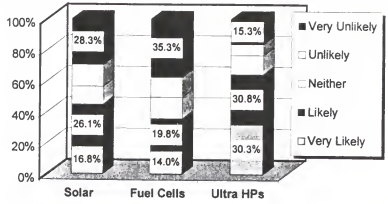

Figure 5.15. Frequency distribution of consumer willingness-to-pay for "soft-cost" benefits excluding tangible ROI. Between 33.8% and 61.1% select "futuristic" sustainable alternatives regardless of hard-cost payback.

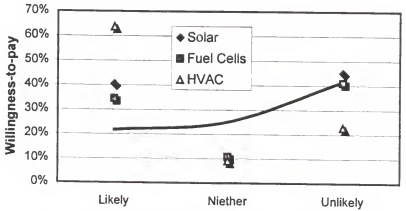

Figure 5.16. Trend analysis of consumer willingness-to-pay for "soft-cost" benefits excluding tangible ROI. Differences between "likely," "neither" and "unlikely" responses significant ($\rho < 0.03, 0.01, 0.01$). Correlation among solar, fuel cell and ultra-HVAC groups moderate to high ($r = 0.53\text{-}0.99$).

Results from Figures 5.15-5.16 indicate that willingness-to-pay for soft cost benefits excluding hard cost ROI vary widely from 33.8% to 61.1%, presumably as a result of either differences in familiarity with the advanced alternatives presented by the survey instrument or the level of "soft" cost benefits consumers perceive to be provided by the respective alternatives. Regardless, consumers within the sample population appear to have a slightly higher likelihood of selecting sustainable alternatives that do not demonstrate a positive ROI but protect the human health and the health of the environment than those that are unlikely to invest in sustainable alternatives for soft cost benefit alone. When comparing those approximate 40% of consumers that were unwilling to pay for soft cost benefits, more than 80% chose either a low, moderate or high cost, high return window, watergy or HVAC alternative. This means that fewer than 10% of respondents were unwilling to invest in either the hard or soft cost benefits of energy and watergy alternatives.

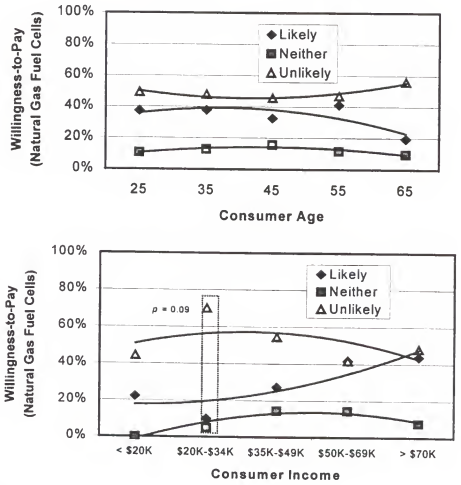

Figure 5.17. Trend analysis comparing *age* and *income* to consumer willingness-to-pay for "soft-cost" benefits of natural gas fuel cells regardless of "hard-cost" payback. Significant differences between observed and expected values from \$20K-\$34K (ρ = 0.09) income group.

Data from the trend analysis in Figure 5.17 shows that consumer willingness-to-pay for sustainable alternatives regardless of monetary "payback" remained very consistent among consumer ages and levels of income. Notable exceptions were found willingness-to-pay for natural gas fuel cells and ultra-efficient air-conditioning systems. Consumers with lower incomes ($20K-$34K, ρ = 0.09) were less likely to invest in the soft cost benefits of residential scale fuel cells, which catalytically reform simple hydrocarbon fuels such as natural gas and propane to hydrogen for near emissions-free electrical power and waste heat for domestic hot water. Overall, more than 60% of consumers were likely to invest in ultra-high efficiency HVAC systems such as 18+ SEER dual-variable speed compressor technologies, that due to emerging demand, remain very costly and may not provide the "payback" possible with more mature, commercially available12-16 SEER systems. Notable exceptions are consumers age 55-65 and those having incomes less than $20K, who were significantly less likely to invest in 18+ SEER soft cost benefits alone (Figure 5.18).

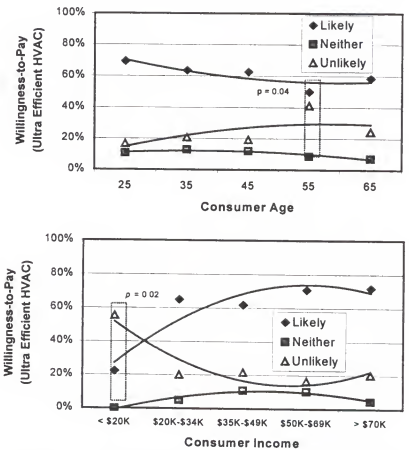

Figure 5.18. Trend analysis comparing *age* and *income* to consumer willingness-to-pay for "soft-cost" benefits of ultra efficient HVAC regardless of "hard-cost" payback. Significant differences between observed and expected values from 55-65 (ρ = 0.04) age group. Significant differences between observed and expected values from <$20K ($\rho$ = 0.02) income group.

Demographics. Correlation among consumer demographics was essential to identify consumer profiles that are most receptive to the cost-benefit performance of either low, moderate or high cost, high return sustainable alternatives. For example, respondents age 45-54 in professional occupations with annual incomes greater than $65K are nearly twice as likely to invest in high cost, high return alternatives than respondents less than 35 years of age having incomes of $34K or less. Trend analysis comparing race and age to level of income are provided in Figure 5.19 below.

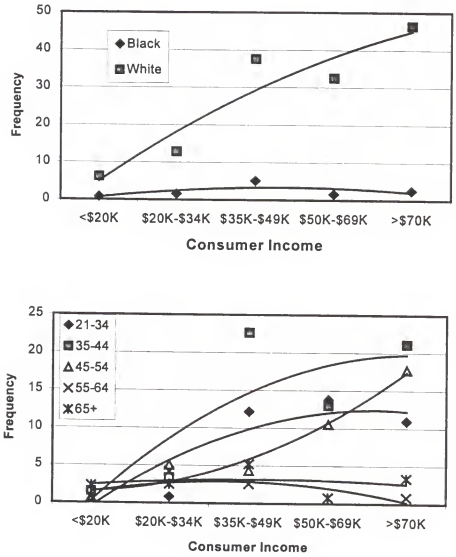

Figure 5.19. Trend analysis comparing consumer demographics to level of income.

Civano Tuscson Solar Village Market Analysis. A survey analysis, similar to that for high-growth metropolitan areas of north, central and south Florida, was developed by MPM Research & Consulting to determine the market potential for *Civano*, a mixed sustainable community of approximately 2,500 resource efficient homes. A comprehensive research survey was conducted among 300 heads of households in the Tucson metropolitan area during September 1995 using random sample telephone interviews (95%, +/- 6%).

Although the market survey assessments for *Civano* and high-growth Florida remain distinctly different, both were developed to assess the market potential for sustainable residential development. The qualitative approach of the *Civano* instrument surveyed the broad domain of community development, from socioeconomics to aesthetics, from building components to community level design. As an appropriate complement, the quantitative approach of the high-growth Florida survey examined the effects that life-cycle cost-benefit had on consumer willingness-to-pay, and more specifically, the changes in willingness-to-pay relative to changes in consumer demographics. In spite of these and other differences, several comparisons between the two research initiatives were made to reinforce and strengthen the data results of each.

Results indicated that nearly all respondents expressed significant interest in the Civano concept in 1995. A further 82% would be willing to pay more for sustainable alternatives if the added capital costs could be recouped through utility savings, compared to 89% for similar concepts in high-growth Florida in 1998. 79% of consumers surveyed in metropolitan Tucson were found to have "great" appeal for watergy efficient showers, toilets, and dishwashers, compared to more than 87% in high-growth metropolitan Florida. 72% of residents in high-growth Florida had a moderate to high interest in energy alternatives whereas 62% or more of residents in Tucson voiced an interest in similar alternatives such as active and passive solar technologies. These and other key findings of both research surveys indicate that consumers understand that resource reduction is both environmentally necessary and economically viable. Survey results indicated that most consumers are willing to pay more initially for alternatives that reduce life-cycle costs equal to or greater than the amount of the added capital investment. As a result, both research endeavors support the theory that market forces can be utilized to achieve a balance between economic and environmental sustainability.

Conclusions

Although clear trends have emerged between consumer willingness-to-pay and a) cost and non-cost issues, b) types of cost structures, c) capital costs and life-cycle return, and d) demographics; consumer behavior remains a complex social phenomena that cannot be explained by a single critical factor, making attempts to determine causality with any degree of certainty very

difficult without considerably more in-depth analysis. However, with this key limitation of research noted, *Market Survey Assessments* have successfully provided the foundation to 1) correlate the affects of capital and life-cycle costs on consumer willingness-to-pay when other behavioral domains and consumer demographics are known, and 2) identify statistically significant differences in willingness-to-pay from norms and averages based on specific consumer profiles.

In summary, consumers prioritized level of willingness-to-pay according to total return-on-investment, meaning willingness-to-pay changed proportional to changes in total return as that the vast majority of consumers chose high capital cost, high return alternatives. Results from Table 5.13 also indicated that savings-to-investment (SIR) ratio was not as significant a consideration, meaning that if consumers viewed the purchase of a sustainable alternative as an "opportunity" cost, they should have chosen low cost, low return alternatives, which had the highest SIR, and invested the balance of their available resources elsewhere. As a result, the most fundamental discovery is that although incremental changes in capital costs, SIR and CCR are contributing factors, the variable most influencing consumer willingness-to-pay was clearly rate-of-return and subsequent ROI_{max}. Since, consumers demonstrated no apparent inclination to view investment in sustainable energy and watergy alternatives as an "opportunity" cost, discounting life-cycle returns to account for lost opportunity returns was eliminated from *Life-Cycle Cost Modeling*.

With the results of *Life-Cycle Cost Modeling* and *Market Assessment Surveys* complete, a *Decision Analysis Matrix* can be developed to "match" sustainable energy and watergy alternatives to specific consumer profiles in order to maximize market acceptance and subsequent economic benefits. Once completed, industry professionals may have the information necessary to provide competitive alternatives to conventional building practices, allowing market forces to become the primary driver for the integration of sustainability into residential development.

CHAPTER 6
DECISION ANALYSIS MATRIX

Introduction

To provide industry with a simple matrix that would allow professionals to efficiently select sustainable energy and watergy alternatives based on level of market demand, the integrated and amortized performance of each alternative in each region was plotted within the domains of observed willingness-to-pay profiles from major consumer demographic groups. As an example, the cost-benefit of sustainable alternatives was plotted as function of SIR and CCR, and then overlaid by the SIR and CCR willingness-to-pay domains of various age and income groups. If the SIR and CCR performance of a sustainable alternative was plotted above the MARR line of a target demographic group, then the alternative would be assumed to meet the MARR of the demographic group and would be selected (Figures 6.1-6.6). A sample software "program" was also developed to provide an example of a computerized application of this process.

The decision analysis matrix was intended as a method of applying the research results from life-cycle cost modeling and market survey assessments. Cost variables used to construct the matrices included CCR and SIR since "break-even point," capital costs and ROI_{max} were found to have the most significant impact on consumer MARR. Among demographic variables, age and income were shown to have the most MARR variability.

Age and Income Demographic Trends

The method used to develop the decision analysis matrix was to evaluate the affects of several CCR and SIR patterns on consumer willingness-to-pay for different age and income groups. This was accomplished by plotting the *individual* and *cumulative* CCR and SIR of sustainable energy and watergy alternatives in the 15 year CCR package from Chapter 4. Next, willingness-to-pay domains were plotted as an "overlay" using the age and income specific MARR data from Chapter 5. In practice, those individual and cumulative alternatives, whose SIR and CCR fell within the domain of a desired SIR and CCR pattern from a specific demographic group, would then be selected for that group.

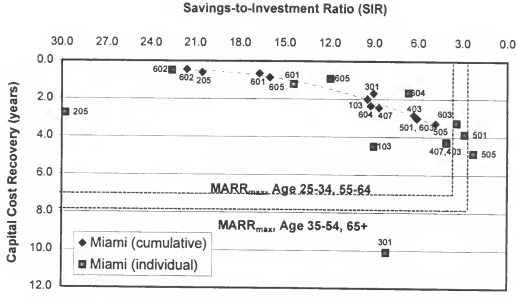

Figure 6.1. Comparison of MARR and consumer age, Miami region.

As shown in Figures 6.1-6.6, the SIR and CCR of individual and cumulative energy and watergy alternatives in the 15 year CCR package from Chapter 4 was plotted for each region. Next, age and income preference for a) low cost, low return b) moderate cost, moderate return and c) high cost, high return energy alternatives from Chapter 5 were evaluated. *Within* each of the energy groups of low, moderate and high cost, high return alternatives, the SIR and CCR of the alternative that received the most "willingness-to-pay" response was calculated for each age and income group. The largest value *between* groups, or, the highest value of SIR and CCR that a majority of homeowners were willing to pay for ($MARR_{max}$), was determined for each age and income group.

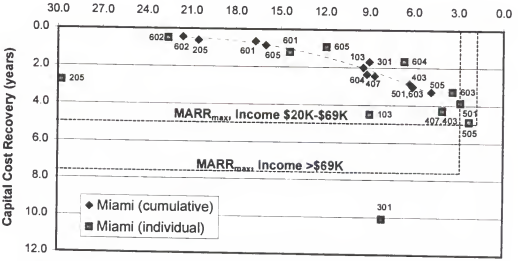

Figure 6.2. Comparison of MARR and consumer income, Miami region.

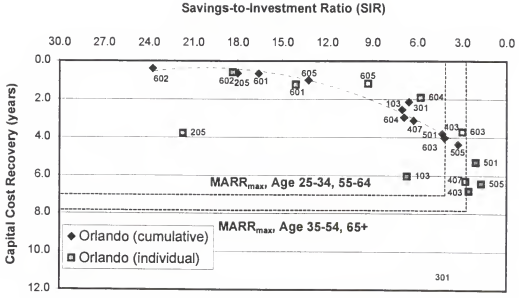

Figure 6.3. Comparison of MARR and consumer age, Orlando region.

Analysis of findings from Chapter 5 showed that consumers age 25-34 demonstrated less willingness-to-pay "tolerance" than older consumers. Specifically, willingness-to-pay for consumers in this age group declines as CCR approaches 7 years and SIR falls below 4.0. As a result, fewer sustainable energy and watergy alternatives would be acceptable to owner-occupants age 25-34. By contrast, the willingness-to-pay for consumers 35+ declines as CCR approaches 8 years and SIR falls below 3.0, meaning that more alternatives would receive market support from older consumers. Similarly, as income increased, so did consumer willingness-to-pay.

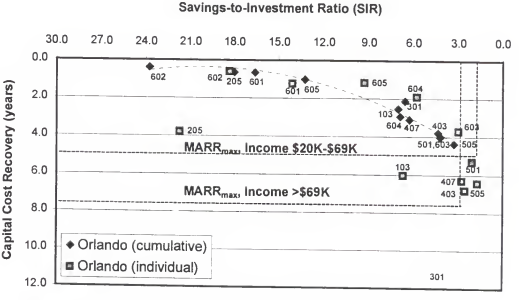

Figure 6.4. Comparison of MARR and consumer income, Orlando region.

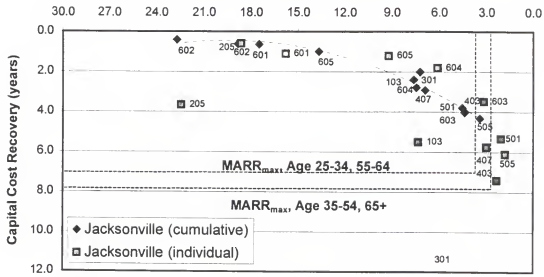

Figure 6.5. Comparison of MARR and consumer age, Jacksonville region.

Since few statistically significant differences were found in consumer willingness-to-pay between north, central and south regions, MARR was factored as a function of CCR and SIR from the aggregate population. As a result, the $MARR_{max}$ domain is the same for both age and income for all three regions as shown in Figures 6.1-6.6. As expected, each of these "fixed" demographic domains within each region included different combinations of energy and watergy alternatives as climatic influences and cost structures changed from one region to another.

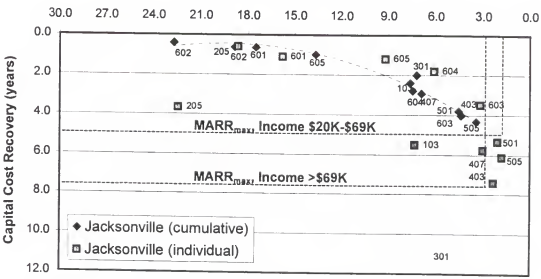
Savings-to-Investment Ratio (SIR)
30.0 27.0 24.0 21.0 18.0 15.0 12.0 9.0 6.0 3.0 0.0
Capital Cost Recovery (years)
0.0 2.0 4.0 6.0 8.0 10.0 12.0
602 205 602 601 601 605 605 301 604 103 604 407 205 501 403 603 603 505 103 501 407 505 403
MARR$_{max}$, Income $20K-$69K
MARR$_{max}$, Income >$69K
Jacksonville (cumulative)
Jacksonville (individual)
301

Figure 6.6. Comparison of MARR and consumer income, Jacksonville region.

Table 6.1 summarizes sustainable energy and watergy alternatives selected specific to each demographic subgroup according to the desired SIR and CCR of each. Modeled relative to the differences in climatic performance, adjusted capital costs, current and projected energy and water rates from each region, the willingness-to-pay for each demographic subgroup is further simplified by a "yes" (Y) or "no" (N) response. A "Y" designator identifies an alternative that falls above the $MARR_{max}$ domain of a demographic subgroup (Figures 6.1-6.6), meaning that under any of the modeled conditions, the SIR and CCR of the alternative meets or exceeds a desired SIR and CCR of the consumer subgroup. A "N" designator identifies an alternative that falls outside of the $MARR_{max}$ domain of a demographic subgroup, meaning that the SIR and CCR of the alternative does not meet a desired SIR and CCR of the consumer subgroup as determined from the survey.

Table 6.1. Single demographic decision analysis matrix.

	Miami				Orlando				Jacksonville			
	Age		Income		Age		Income		Age		Income	
	25-34	>35	$20-69K	>$69K	25-34	>35	$20-69K	>$69K	25-34	>35	$20-69K	>$69K
602	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
601	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
205	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
605	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
103	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y
604	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
301	N	N	N	N	N	N	N	N	N	N	N	N
407	Y	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
403	Y	Y	Y	Y	N	N	N	N	N	N	N	N
501	N	Y	N	Y	N	N	N	N	N	N	N	N
603	Y	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
505	N	Y	Y	N	N	N	N	N	N	N	N	N

Since the 15 year CCR package of sustainable energy and watergy alternatives used in Table 6.1 contained several alternatives that exceeded the maximum return period for any consumer group (<8.0 years), many *individual* alternatives were eliminated (N). However, when the *cumulative* values of sustainable energy and watergy alternatives were considered, those alternatives with very high SIR and short CCR periods were found to more than compensate for alternatives that, individually, would not be acceptable. If Table 6.1 were to present a cumulative "package," nearly all of the energy and watergy alternatives would meet the minimal attractive rate of return of most owner-occupants. SIR and CCR are however, only a few of the many payback variables found to affect consumer willingness-to-pay. SIR and CCR were chosen for this analysis because they represent a common indicator of economic efficiency that can be used to make cost-benefit comparisons among several different investment alternatives.

Computer Applications

As a "product" of this research, both individual and multi-demographic decision matrices were developed using the data sets from the life-cycle cost models and market survey assessments in order to select sustainable energy and watery alternatives based on regional economic, climatic and demographic criteria. The methodology for evaluating the market response to the cost-benefit of sustainable energy and watergy alternatives was therefore "simplified" into a user-friendly, software package as illustrated in the section to follow.

Supplementing a standard software package such as REM/Design™ with the cost-benefit and market survey assessment data and methodology developed herein would enable the user to select sustainable alternatives based on the performance of a given alternative, its "payback," and the consumer willingness-to-pay according to demographic composition. The first step toward selecting sustainable alternatives with optimal market appeal is, however, to determine the consumer composition of the market. As the results of Chapter 5 indicate, consumer willingness-to-pay and MARR are closely related to consumer demographics. *Step 1a* above provides some of the consumer demographics surveyed and found to have a statistically significant relationship to willingness-to-pay. As shown, the screen allows the user to choose any combination of demographics to construct a consumer profile. Further along in the process, alternatives will be selected based on the degree to which the regional specific payback of each alternative complements the MARR of the consumer's demographic composition. Similarly, the second screen, *Step 1b*, defines the general building characteristics necessary to establish a performance and subsequent ROI baseline.

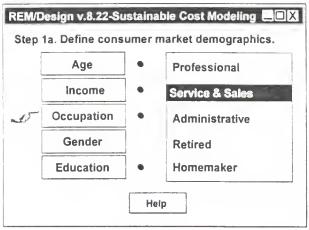

Figure 6.7. Consumer market demographics.

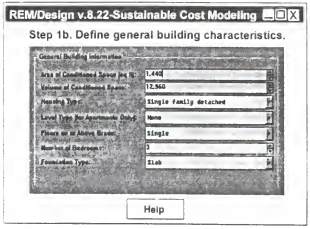

Figure 6.8. General building characteristics.

A region must be defined to calculate climatic influences on performance and apply appropriate resource rate structures. Default heating degree days (HDD), cooling degree hours (CDH) and solar incidence are provided for each region. Default utility rates and capital adjustment factors are also provided. Having established an analysis profile complete with regional consumer and building characteristics, the user may now select which broad categories of sustainable alternatives are of interest for potential buyers. As shown in example *Step 2*, default energy and watergy alternatives have been selected. By selecting the *customize* option however, the user can "build" packages containing select sub-categories of sustainable alternatives from one or more of the options provided. Next, criteria must be established to reduce the number of alternatives to be modeled. Since capital cost, maximum return-on-investment (ROI_{max}), capital cost recovery (CCR) and savings-to-investment ratio (SIR) were shown to have the most statistically significant effect on consumer willingness-to-pay across the aggregate population, these variables have been selected as "screening" criteria representative of consumer specific MARR. The left options column screens alternatives by desired CCR, meaning that in this example, only alternatives achieving CCR in 15 years or less will be considered for comprehensive analysis. The right column provides options for prioritizing qualifying alternatives.

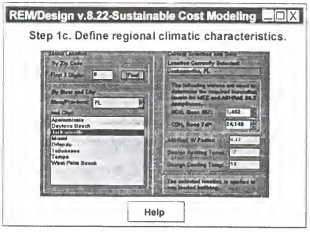

Figure 6.9. Regional climatic characteristics.

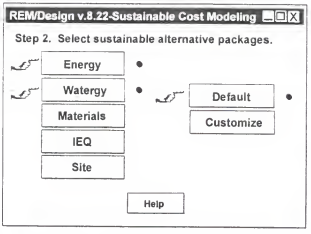

Figure 6.10. Sustainable alternative packages.

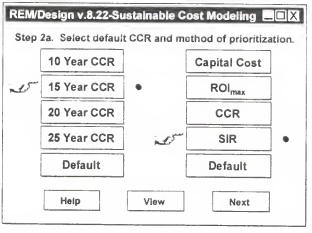

Figure 6.11. Method of prioritization.

Based on the demographic data entered in *Step 1a*, default values can be entered, meaning that life-cycle cost structures most amenable to the consumer profile will be selected automatically. A "short list" of candidate alternatives meeting the CCR and SIR criteria is assembled next. Once the initial screening process in *Step 2a* reduces the number of alternatives to only those that achieve CCR in 15 years or less, the list of candidates are prioritized by SIR. This is necessary because the order that alternatives are added to the comprehensive performance simulation to follow has an effect on the performance and subsequent ROI of each alternative. By prioritizing all CCR ≤15 year candidate alternatives by SIR, the SIR of the cumulative alternatives "package" will be optimized, meaning that if limitations on added capital costs preclude the entire package from being selected, the cumulative performance and ROI of the partial package will have the highest SIR possible. Once a short list of screened alternatives has been assembled, a detailed performance analysis can be executed more efficiently. As illustrated in *Step 3*, the integrated performance simulation is run on the short list of alternatives resulting in the down-select of one alternative for each functional area achieving optimal CCR and SIR.

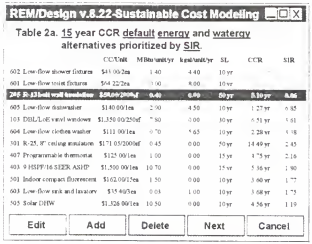
REM/Design v.8.22-Sustainable Cost Modeling
Table 2a. 15 year CCR default energy and watergy alternatives prioritized by SIR
CC/Unit
MBtu/unit/yr
kgal/unit/yr
SIL
CCR
SIR
602 Low-flow shower fixtures $41.00/2ea 1.40 4.40 10 yr
601 Low-flow toilet fixtures $64.22/2ea 0.00 8.00 10 yr
605 Low-flow dishwasher $140.00/1ea 2.90 4.50 10 yr 1.27 yr 9.85
103 DSL/Low-e vinyl windows $1,350.00/250sf 7.50 0.00 30 yr 6.51 yr 1.61
604 Low-flow clothes washer $111.00/1ea 0.70 5.63 10 yr 2.28 yr 4.98
101 R-25, 9" ceiling insulation $171.05/200sf 0.45 0.00 50 yr 14.49 yr 2.45
607 Programmable thermostat $125.00/1ea 1.00 0.00 15 yr 3.75 yr 2.16
403 9 HSPF/16 SEER ASHP $1,500.00/1ea 10.70 0.00 15 yr 5.36 yr 1.90
501 Indoor compact fluorescent $162.00/12ea 1.50 0.00 10 yr 3.60 yr 1.77
603 Low-flow sink and lavatory $35.40/5ea 0.04 1.00 10 yr 3.68 yr 1.75
503 Solar DHW $1,320.00/1ea 10.50 0.00 10 yr 4.56 yr 1.19
Edit
Add
Delete
Next
Cancel

Figure 6.12. Energy and watergy alternatives.

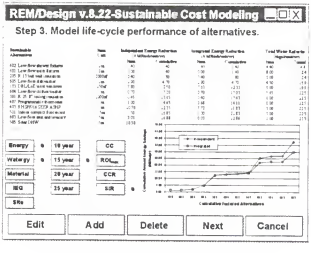

Figure 6.13. Life-cycle performance.

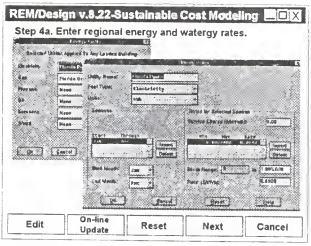

Figure 6.14. Regional energy and watergy rates.

As shown in *Step 3*, the integrated energy and watergy performance simulation summary provides the change in energy (ΔMBtuh/unit/yr) and water (ΔKgal/unit/yr) consumption for both individual and cumulative alternatives. Having completed the performance modeling, the cost-benefit of alternatives that typically have a higher capital cost must be compared to the returns made possible by energy and water resource reduction. To accomplish this, the change in capital costs must be compared to the change in life-cycle utility costs. As *Step 4a* illustrates, rates for water, wastewater, natural gas, electricity or any other metered utility can be selected, as can the capital cost of energy and watergy alternatives. With Internet access, these cost structures can be updated with automated website links to either the regional utilities or material vendors as shown in *Step 4b*. With the performance simulation and rate structures completed, the life-cycle cost-benefit of the CCR ≤15, SIR prioritized alternatives package can be calculated. The change in capital costs with respect to maximum return-on-investment is presented for each individual and cumulative alternative(s). Again, the user has the option to manually edit, add, or delete life-cycle cost-benefit data or entire alternatives as part of a customized package. To account for the time-value of capital investment and life-cycle ROI of sustainable energy and watergy alternatives, amortization schedules can be factored into the "straight-line" ROI process .

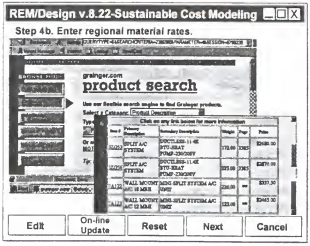

Figure 6.15. Regional material rates.

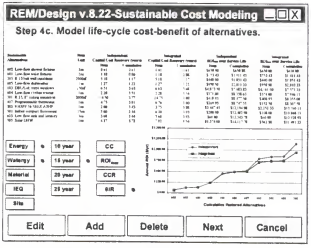

Figure 6.16. Cost-benefit of alternatives.

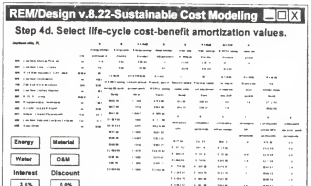

Figure 6.17. Cost-benefit amortization values.

As *Step 4d* illustrates, interest and discount rates can be entered independently for each energy and water resource as well as for the material and life-cycle operation and maintenance of the alternative over its useful service life. Default options can also be selected which include 25 year estimates on energy and water rate inflation relative to predicted general inflation rates for each region. Summary roll-up tables are provided showing the cumulative 1) net-present value (NPV, $\approx ROI_{max}$), 2) capital costs, 3) annual ROI, 4) SIR, 5) annual NPV, and 6) CCR for each alternative.

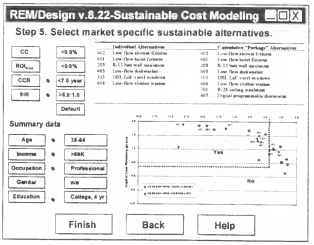

Figure 6.18. Market specific alternatives.

Finally, a decision analysis matrix is presented in *Step 5* to enable the user to select market specific sustainable alternatives. First, the desired cost structure criteria are entered consisting of one or more of capital cost (CC), ROI_{max}, CCR, or SIR variables. Next, the desired values for each of the selected cost structure criteria are entered. Again, this may be accomplished manually or by selecting the default option, which would automatically provide consumer specific values for each criterion based on the data gathered by the market survey assessments in Chapter 5. The summary data for the consumer demographic profile is again displayed, leaving the option for any final changes. Based on the selected consumer demographics and life-cycle cost-benefit of the sustainable alternatives, a plot showing the CCR (y-axis) and SIR (x-axis) performance of the cumulative package is presented. The graphic display in *Step 5* clearly shows the declining marginal utility of the alternatives package, as both the cumulative CCR and SIR decline as added alternatives are factored. Plotting the selected CCR and SIR preference of the consumer profile on the respective axes, a boundary line clearly demarcates which alternatives meet the willingness-to-pay profile of the consumer and which do not.

Conclusion

The decision matrix illustrated in this chapter demonstrates that a methodology could be developed to satisfy an industry need for a simple decision tool that would provide design-build professionals the ability to efficiently select marketable alternatives without cost intensive value-engineering analysis. Again, results indicated that significant relationships exists between consumer demographics and willingness-to-pay. By integrating the life-cycle cost modeling with market survey assessments, a methodology for predicting consumer willingness-to-pay was presented.

CHAPTER 7
ECO-ECONOMIC IMPACTS

Introduction

Based on the descriptive and analytical data derived from chapters 2, 4, 5 and 6, an estimate of the consumer response and corresponding environmental impact of using sustainable energy and watergy alternatives in the existing dwelling stock is presented in this chapter. Similarly, an estimate of the consumer response and corresponding environmental impact of using sustainable energy and watergy alternatives in the future dwelling stock from 2000-2020 is also presented. An internalization approach quantifies the cost of emissions abatement per unit of energy generated based on the total energy conserved by sustainable alternatives over their useful life and discounts this amount from the capital cost of sustainable energy and watergy alternatives. The result of reduced capital costs through this internalization approach is reflected as an increase in market efficiency and a decrease in emissions through conservation.

Environmental and Economic Linkages

Energy constitutes a critical input in sustaining the Nation's economic growth and development. There are, however, byproducts of energy utilization that have an undesirable effect on the environment, including the uncontrolled release of nitrogen oxides, sulfur dioxide, carbon oxides, heavy metals, particulates and organic pyrolysis compounds. NO_x and CO_2 emissions in particular, absorb radiant solar energy, contributing to the global greenhouse effect.

Based on an average 13×10^9 kWh per month generation rate, predicted 1998 fossil-fueled power generation will account for no less than 1.56×10^{11} kilowatt hours. Of this, approximately half or 7.8×10^{10} kWh is consumed by the residential sector and at least 65% or 5.07×10^{10} kWh is used by the singled-family dwelling stock. Fifty percent or more of the remaining energy, some 2.54×10^{10} kWh, is used by owner-occupied <2,500sf units in high-growth regions of north, central and south Florida. Based on an average of 7,500 kWh per single-family detached unit saved, the aggregate regions of north central and south Florida could reduce energy consumption as much as 1.4×10^{10} kWh, or nearly 50% as a result of implementing sustainable energy and watergy alternatives.

Results of the life-cycle cost modeling in Chapter 4, suggest that typical 1995 MEC compliant single-family detached housing in Florida could conceivably reduce total energy use by 40% or more through the use of sustainable energy and watergy alternatives. Using the latest data available from 1996, a year with similar power output as projected for 1998, corresponding emissions tonnage per fuel source are provided in Table 7.1. Analysis of the fossil fuel component, which contributes approximately 76% of Florida's electricity, indicates that for every kilowatt hour (kWh) generated and consumed, 0.008lb, 0.005lb, and 1.3lb respectively of SO_2, NO_x and CO_2 will be produced.

Table 7.1. Estimated emissions from fossil-fueled steam electric generating units at Florida electric utilities, (in thousand tons) (24).

	Coal	Petroleum	Gas	Nuclear	Totals
Energy (MkWh)*	4,551 (38%)	2,614 (22%)	1,912 (16%)	2,869 (24%)	11,963 (100%)
Sulfur Dioxide	445	185	<0.5	<0.5	630
Nitrogen Oxides	255	40	42	<0.5	337
Carbon Dioxide	66,983	19,307	10,997	45	97,332

* Estimated based on documented March/April 1998 generation rates.

Summary Characteristics of High-Growth Florida. Since statistically significant differences in consumer willingness-to-pay were found specifically between age and income, only these demographics were used to stratify the high-growth regions of north, central and south Florida found in Tables 7.3, 4 and 6. MARR values were then established for the more than 1,592,176 owner-occupants in the immediate Jacksonville, Orlando, and Miami metropolitan areas based on the age and income distribution found within the market survey assessments as shown in Table 7.2.

Table 7.2. Age and income distribution of owner-occupants in high-growth regions of Florida.

AGE & INCOME	<$20K	$20K-$34K	$35K-$49K	$50K-$69K	>$69K	TOTALS
25-34	18,502 (1.2%)	8,833 (0.6%)	116,881 (7.4%)	135,993 (8.6%)	107,334 (6.8%)	387,543 (24%)
35-44	18,502 (1.2%)	28,370 (1.8%)	223,562 (14.1%)	126,440 (8.0%)	204,456 (12.9%)	601,330 (38%)
45-54	8,833 (0.6%)	47,906 (3.1%)	38,138 (2.5%)	107,334 (6.8%)	175,798 (11.1%)	378,009 (23%)
55-64	8,833 (0.6%)	38,138 (2.5%)	28,370 (1.8%)	8,833 (0.6%)	8,833 (0.6%)	93,007 (7%)
65+	18,502 (1.2%)	28,370 (1.8%)	47,906 (3.1%)	8,833 (0.6%)	28,370 (1.8%)	131,981 (8%)
TOTALS	73,472 (4%)	151,617 (9%)	454,863 (29%)	387,433 (25%)	524,791 (33%)	1,592,176 (100%)

As Table 7.2 illustrates, consumers age 25-54 with incomes of $35K or greater compose 1,187,798 or 75.3% of owners occupying <2,500sf single-family housing in high-growth regions of Florida.

Table 7.3. Estimated annual cost-benefit and environmental impact of implementing <15 year CCR energy and watergy "package" in *current* <2500sf single-family detached housing stock in high-growth regions of north, central and south Florida (in 1998 dollars).

	South Region (Miami)				Central Region (Orlando)				North Region (Jacksonville)			
	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K
Willingness-to-pay												
Owner-Occupants	215,297	592,672	82,248	319,317	39,720	109,345	15,174	58,912	28,390	78,151	11,204	42,106
Alternatives	602-403	602-505	602-403	602-603	602-407	602-505	602-301	602-505	602-407	602-505	602-301	602-505
Cost-Benefit												
Δ Capital Cost ($K)/capita	2.6	3.7	2.6	2.7	2.0	5.1	1.9	5.1	1.9	4.8	1.8	4.8
Δ Cum. Capital Cost ($M)	559.8	2,192.9	213.9	862.2	79.4	557.7	28.8	300.5	53.9	375.0	20.2	202.1
Annual NPV ($K)/capita	0.9	1.1	0.9	0.9	0.7	1.1	0.7	1.1	0.6	1.0	0.5	1.0
Cum. Annual NPV ($M)	196.1	651.9	74.0	287.4	27.8	120.3	10.6	64.8	17.0	78.8	5.6	42.1
Conservation												
Δ kWh/yr/capita	7.5×10^3	9.9×10^3	7.5×10^3	7.9×10^3	4.6×10^3	9.8×10^3	4.2×10^3	9.8×10^3	5.1×10^3	9.9×10^3	4.9×10^3	9.9×10^3
Cum. Δ kWh/yr	1.6×10^9	5.9×10^9	0.6×10^9	2.5×10^9	0.2×10^9	1.1×10^9	0.1×10^9	0.6×10^9	0.1×10^9	0.8×10^9	0.1×10^9	0.4×10^9
Δ kgal/yr/capita	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2
Cum. Δ kgal/yr	0.5×10^7	1.3×10^7	0.2×10^7	0.7×10^7	0.1×10^7	0.3×10^7	0.1×10^7	0.2×10^7	0.1×10^7	0.2×10^7	0.1×10^7	1.0×10^7
Emissions Reduction												
Δ SO_2, lbs/yr/capita	6.0×10^1	7.9×10^1	6.0×10^1	6.3×10^1	3.7×10^1	7.8×10^1	3.4×10^1	7.8×10^1	4.1×10^1	7.9×10^1	3.9×10^1	7.9×10^1
Cum. Δ SO_2, lbs/yr	1.3×10^7	4.6×10^7	0.5×10^7	2.0×10^7	0.2×10^7	0.9×10^7	0.1×10^7	0.5×10^7	0.1×10^7	0.6×10^7	0.1×10^7	0.3×10^7
Δ NO_x, lbs/yr/capita	3.8×10^1	5.0×10^1	3.8×10^1	4.0×10^1	2.3×10^1	4.9×10^1	2.1×10^1	4.9×10^1	2.6×10^1	5.0×10^1	2.5×10^1	5.0×10^1
Cum. Δ NO_x, lbs/yr	0.8×10^7	2.9×10^7	0.3×10^7	1.3×10^7	0.1×10^7	0.6×10^7	0.1×10^7	0.3×10^7	0.1×10^7	0.4×10^7	0.1×10^7	0.2×10^7
Δ CO_2, lbs/yr/capita	1.0×10^4	1.3×10^4	0.9×10^4	1.0×10^4	0.6×10^4	1.3×10^4	0.6×10^4	1.3×10^4	0.7×10^4	1.3×10^4	0.6×10^4	1.3×10^4
Cum. Δ CO_2, lbs/yr	1.9×10^9	7.7×10^9	0.7×10^9	3.2×10^9	0.3×10^9	1.4×10^9	0.1×10^9	0.8×10^9	0.1×10^9	1.0×10^9	0.1×10^9	0.5×10^9

Table 7.4. Estimated annual cost-benefit and environmental impact of implementing <15 year CCR energy and watergy "package" in projected 2000-2020 <2500sf single-family detached housing stock in high-growth regions of north, central and south Florida (in 1998 dollars).

	South Region (Miami)				Central Region (Orlando)				North Region (Jacksonville)			
	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K
Willingness-to-pay												
Owner-Occupants	287,063	790,229	109,664	425,756	52,960	145,793	20,232	78,549	37,853	104,201	14,939	56,141
Alternatives	602-403	602-505	602-403	602-603	602-407	602-505	602-301	602-505	602-407	602-505	602-301	602-505
Cost-Benefit												
Δ Capital Cost ($K)/capita	2.6	3.7	2.6	2.7	2.0	5.1	1.9	5.1	1.9	4.8	1.8	4.8
Δ Cum. Capital Cost ($M)	746.4	2,923.9	285.2	1,149.6	105.9	743.6	38.4	400.7	71.9	500	26.9	269.5
Annual NPV ($K)/capita	0.9	1.1	0.9	0.9	0.7	1.1	0.7	1.1	0.6	1.0	0.5	1.0
Cum. Annual NPV ($M)	261.5	869.2	98.7	383.2	37.1	160.4	14.1	86.4	22.7	105.1	7.5	56.1
Conservation												
Δ kWh/yr/capita	7.5×10^3	9.9×10^3	7.5×10^3	7.9×10^3	4.6×10^3	9.8×10^3	4.2×10^3	9.8×10^3	5.1×10^3	9.9×10^3	4.9×10^3	9.9×10^3
Cum. Δ kWh/yr	2.1×10^9	7.8×10^9	0.8×10^9	3.3×10^9	0.3×10^9	1.5×10^9	0.1×10^9	0.8×10^9	0.1×10^9	1.1×10^9	0.1×10^9	0.5×10^9
Δ kgal/yr/capita	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2
Cum. Δ kgal/yr	0.7×10^6	1.7×10^6	0.3×10^6	0.9×10^6	0.1×10^6	0.4×10^6	0.1×10^6	0.3×10^6	0.1×10^6	0.3×10^6	0.1×10^6	1.3×10^6
Emissions Reduction												
Δ SO_2, lbs/yr/capita	6.0×10^1	7.9×10^1	6.0×10^1	6.3×10^1	3.7×10^1	7.8×10^1	3.4×10^1	7.8×10^1	4.1×10^1	7.9×10^1	3.9×10^1	7.9×10^1
Cum. Δ SO_2, lbs/yr	1.7×10^7	6.1×10^7	0.7×10^7	2.7×10^7	0.3×10^7	1.2×10^7	0.1×10^7	0.7×10^7	0.1×10^7	0.8×10^7	0.1×10^7	0.4×10^7
Δ NO_x, lbs/yr/capita	3.8×10^1	5.0×10^1	3.8×10^1	4.0×10^1	2.3×10^1	4.9×10^1	2.1×10^1	4.9×10^1	2.6×10^1	5.0×10^1	2.5×10^1	5.0×10^1
Cum. Δ NO_x, lbs/yr	1.1×10^7	3.9×10^7	0.4×10^7	1.7×10^7	0.1×10^7	0.8×10^7	0.1×10^7	0.4×10^7	0.1×10^7	0.5×10^7	0.1×10^7	0.3×10^7
Δ CO_2, lbs/yr/capita	0.9×10^4	1.3×10^4	0.9×10^4	1.0×10^4	0.6×10^4	1.3×10^4	0.6×10^4	1.3×10^4	0.7×10^4	1.3×10^4	0.6×10^4	1.3×10^4
Cum. Δ CO_2, lbs/yr	2.5×10^9	9.9×10^9	0.9×10^9	4.2×10^9	0.4×10^9	1.9×10^9	0.1×10^9	1.1×10^9	0.1×10^9	1.3×10^9	0.1×10^9	0.7×10^9
Capital Cost Subsidies												
Reduction/year/capita	$ 338	$ 457	$ 338	$ 303	$ 240	$ 457	$ 200	$ 457	$ 240	$ 457	$ 222	$ 457
$REBATE_{1year}$	$1,014	$1,371	$1,014	$ 909	$ 720	$1,371	$ 600	$1,371	$ 720	$1,371	$ 666	$1,371
$REBATE_{5year}$	$1,690	$2,285	$1,690	$1,515	$1,200	$2,285	$1,000	$2,285	$1,200	$2,285	$1,100	$2,285
$REBATE_{7year}$	$2,366	$3,199	$2,366	$2,121	$1,680	$3,199	$1,400	$3,199	$1,680	$3,199	$1,554	$3,199
$REBATE_{10year}$	$3,380	$4,570	$3,380	$3,030	$2,400	$4,570	$2,000	$4,570	$2,400	$4,570	$2,220	$4,570

As Tables 7.3 and 7.4 indicate, the cost-benefit for emissions reduction through conservation is advantageous for both energy producers and consumers. Again, any of the individual energy and watergy alternatives used for this illustrative analysis will provide a capital cost recovery (CCR) in less than 15 years. When integrated, these alternatives provide CCR in as few as 3 years, depending on the NPV of regional cost adjustments, discounting, etc. Without any subsidies to stimulate added market interest, these integrated "packages" of energy and watergy alternatives provide consumers a savings to investment ratio no less than 2:1 and in some cases, as high as 6:1 over their O&M life-cycle.

Table 7.4 illustrates that significant environmental benefits are possible by utilizing sustainable energy and watergy alternatives, assuming that in this case, all existing single-family detached units and those expected to enter dwelling stock from 20000-2020 were 1995 MEC compliant. Based on the number of owner-occupants expected by 2020 in high-growth Florida and their respective "willingness-to-pay" by cross-section, the economic and environmental impacts of sustainable energy and watergy alternatives selected demographically has been estimated. Again, based on the life-cycle cost modeling and market survey assessments, research has found that consumer MARR is different among those in different age and income groups. By stratifying the population into regions and consumer demographic sub-groups, the projected market elasticity for sustainable alternatives, and their subsequent impacts, was more accurately quantified.

Based on maximum market elasticity by 2020, results indicate that $840.2 million per year worth of *cost of abatement* emissions reductions are attainable through energy and watergy resource conservation, or the elimination of approximately 15×10^7 lbs of NO_x, 10×10^7 lbs of SO_2, and 23×10^9 lbs of CO_2. Again, cost of abatement simply means the expense required to remove "stack" emissions at the source of generation, such as a coal-fired electricity generation plant. Depending on the number of alternatives selected specific to each demographic group in each region, the unsubsidized capital cost investment ranges from approximately $1,800 to $5,100 per capita (Table 7.4). By comparison, the NPV of annual "payback" from energy savings ranges from $500 to $1,100 per capita, resulting in an average CCR of 3.5 years and a SIR of 4.4:1.0. As a result, the projected 2.1 million owner-occupants expected in high-growth single-family detached housing by 2020 could realize an annual payback of $2.1 billion for a $7.3 billion capital investment into sustainable energy and watergy alternatives.

Internalizing Externalities. The environmental impacts caused by emissions and other negative consequences of energy and watergy resource utilization (i.e., habitat destruction, thermal pollution, watershed destruction) are known as "externalities" since the cost of these destructive acts often accrue to someone other than the parties involved in the activity. To the extent that these negative impacts remain unaccounted for, the cost of energy utilization remains lower than what it would otherwise be if the cost of these burdens imposed on society and future generations were also included. As a result, current market return-on-investment for sustainable energy and watergy alternatives remains lower than it would if energy (and water) resources were not undervalued and discounted. If the "true cost" of energy utilization were internalized into the utility rate structure, the returns on sustainable investments would improve, and similarly, the consumer willingness-to-pay would improve across all demographic domains.

In terms of Pigouvian theory, the appropriate method for accounting for these externalities is to tax the producers by an amount equal to the magnitude of damages caused (23). The Pigouvian prescription is embedded in the notion that economic efficiency would be increased by government regulation. Yet in a market economy, no single instrument such as tax is likely to fully account for all damages and costs to society, since these damages are difficult to account for holistically. Perhaps a more sound approach is to address adverse actors, such as energy emissions, from the point-source and thus eliminate its uncontrolled release. In this later scenario, the cost of removing contaminates from emissions could be more easily accounted for and internalized. Without the release of SO_2, there would be no need for nebulous calculations involving the environmental impacts of SO_2 emissions. This approach however, also does not fully account for the costs for other types of non-emissions related externalities associated with energy utilization.

Conservation however, remains the best "technology" available to mitigate externalities since it eliminates the environmental impacts from the entire "fuel cycle." A fuel cycle is the physical and chemical processes and externalities generated during the transformation of usable energy from a specific fuel or resource, including primary extraction, transportation, storage, processing, conversion and waste disposal. The cost society is willing to pay to internalize some of the negative effects of the fuel cycle from either the "direct damage estimation" or "cost of abatement" approach should be credited to technologies which eliminate those same externalities through conservation. This *implied valuation* approach begins with the assumption that the cost of required control measures provides a reasonable indication of what society is willing to pay to reduce pollution. If the cost of reducing SO_2 for example is $0.85/lb, then the value of reductions from alternative sources like conservation should worth an equal or greater amount.

Table 7.5. Valuing energy-related emissions externalities at the marginal cost of control (23).

Pollutant	Massachusetts case-study value	Nevada case-study value	California case-study value	Basis for value
Nitrogen oxides	$7,200/ton	$7,480/ton	$9,100/ton	Selective catalytic reduction on turbine
Sulfur dioxide	$1,700/ton	$1,716/ton	$4,486/ton	Stack flue gas scrubbing system
Carbon dioxide	$24/ton	$24/ton	$9/ton	Biological respiratory process removal
VOCs & ROGs	$5,900/ton	$1,012/ton	$4,236/ton	Control technologies for ozone non-attainment areas
PM_{10}	$4,400/ton	$4,598/ton	$4,608/ton	Electrostatic precipitator with low resistivity fly ash

By internalizing the cost-benefit of emissions reduction in the form of a capital cost subsidy, the life-cycle ROI of sustainable energy and watergy alternatives is enhanced. As shown in Table 7.4, a capital cost subsidy equal to the cost of emissions abatement was determined for each of the four demographic "breakouts" from each region using the CCR <15yr package of alternatives. In this concept, the unit cost of abatement ($3.60/lb NO_x, $0.85/lb SO_2, $0.01/lb CO_2) was factored by the average quantity of emissions (0.008lb/kWh NO_x, 0.005lb/kWh SO_2, 1.3lb/kWh CO_2) generated by the single-family detached unit stereotype in high-growth Florida to determine an emissions reduction per year, per capita. This amount was "equivalent" to the annual cost of abatement to remove these target stack emissions, and could be factored by a value equal to or less than the expected service life of the sustainable energy and watergy alternatives, representing the total value of emissions abatement possible. Since regulators, policy makers, and private industry would likely want to know the minimum subsidy necessary to stimulate enough market interest to meet emissions reduction through conservation, subsidies internalizing the cost of abatement were evaluated.

Assuming that emissions reductions would require the implementation of all alternatives for all demographic subsets in all regions, a minimum capital cost subsidy was determined. Results in Figure 7.1 indicated that internalizing a 3-year cost of abatement would reduce capital costs enough to stimulate willingness-to-pay for all alternatives for all demographic subsets in the south region. For the north and central regions, a 7-year cost of abatement would have to be internalized to reduce capital cost sufficiently to stimulate willingness-to-pay for all alternatives as a result of higher original capital costs and a lower NPV of conservation payback.

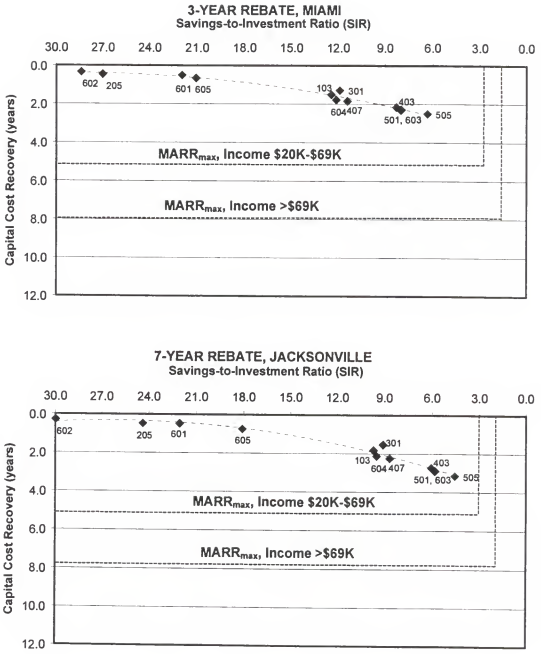
3-YEAR REBATE, MIAMI
Savings-to-Investment Ratio (SIR)
30.0 27.0 24.0 21.0 18.0 15.0 12.0 9.0 6.0 3.0 0.0
Capital Cost Recovery (years)
0.0 2.0 4.0 6.0 8.0 10.0 12.0
602 205 601 605 103 301 604 407 403 501, 603 505
MARRmax, Income $20K-$69K
MARRmax, Income >$69K
7-YEAR REBATE, JACKSONVILLE
Savings-to-Investment Ratio (SIR)
30.0 27.0 24.0 21.0 18.0 15.0 12.0 9.0 6.0 3.0 0.0
Capital Cost Recovery (years)
0.0 2.0 4.0 6.0 8.0 10.0 12.0
602 205 601 605 301 103 604 407 403 501, 603 505
MARRmax, Income $20K-$69K
MARRmax, Income >$69K

Figure 7.1. Changes in "income" willingness-to-pay based on capital cost subsidies accounting for cost of abatement at 3 and 7 year intervals.

Table 7.6. Change in willingness-to-pay from internalizing cost of abatement for target energy related emissions in Florida. Estimated annual cost-benefit and environmental impact of implementing <15 year CCR energy and watergy "package" in projected 2000-2020 <2500sf single-family detached housing stock in high-growth regions of north, central and south Florida (in 1998 dollars).

	South Region (Miami)				Central Region (Orlando)				North Region (Jacksonville)			
	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K	25-34 $20-69K	35+ $20-69K	25-34 >$69K	35+ >$69K
Willingness-to-pay												
Owner-Occupants	287,063	790,229	109,664	425,756	52,960	145,793	20,232	78,549	37,853	104,201	14,939	56,141
Alternatives	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL
$REBATE_1$ Cost-Benefit												
Δ Capital Cost ($K)/capita	1.6	1.6	1.6	1.6	3.7	3.7	3.7	3.7	3.2	3.2	3.2	3.2
Δ Cum. Capital Cost ($M)	459.3	1,264	175.5	681.2	196.0	539.4	75.2	290.6	121.1	333.4	47.8	179.7
Annual NPV ($K)/capita	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0
Cum. Annual NPV ($M)	315.8	869.2	120.6	468.3	58.3	160.4	22.4	86.4	37.9	105.1	14.9	56.1
$REBATE_1$ Conservation												
Δ kWh/yr/capita	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3	9.9×10^3
Cum. Δ kWh/yr	2.8×10^9	7.8×10^9	1.1×10^9	4.2×10^9	0.5×10^9	1.5×10^9	0.2×10^9	0.8×10^9	0.4×10^9	1.1×10^9	0.2×10^9	0.5×10^9
Δ kgal/yr/capita	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2	2.3×10^2
Cum. Δ kgal/yr	0.7×10^6	1.7×10^6	0.3×10^6	0.9×10^6	0.1×10^6	0.4×10^6	0.1×10^6	0.3×10^6	0.1×10^6	0.3×10^6	0.1×10^6	1.3×10^6
$REBATE_1$ Emission Red.												
Δ SO_2, lbs/yr/capita	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1	7.9×10^1
Cum. Δ SO_2, lbs/yr	2.3×10^7	6.1×10^7	0.9×10^7	3.4×10^7	0.4×10^7	1.2×10^7	0.2×10^7	0.7×10^7	0.3×10^7	0.8×10^7	0.1×10^7	0.4×10^7
Δ NO_x, lbs/yr/capita	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1
Cum. Δ NO_x, lbs/yr/capita	1.4×10^7	3.9×10^7	0.6×10^7	2.1×10^7	0.3×10^7	0.8×10^7	0.2×10^7	0.4×10^7	0.2×10^7	0.5×10^7	0.1×10^7	0.3×10^7
Δ CO_2, lbs/yr	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3	1.3×10^3
Cum. Δ CO_2, lbs/yr	3.7×10^9	9.9×10^9	1.4×10^9	5.5×10^9	0.7×10^9	1.9×10^9	0.2×10^9	1.1×10^9	0.5×10^9	1.3×10^9	0.7×10^9	0.7×10^9

As an alternative to taxation or rate increases to pay for added stack mitigation, subsidizing the capital cost of sustainable energy and watergy alternatives by a percentage of the cost of emissions abated through conservation may stimulate added market investment, reduce negative publicity, and result in greater reductions in both emissions and non-emissions externalities. Table 7.6 indicates that, by internalizing a small part of the life-cycle *cost of abatement* into a capital cost subsidy, the ROI performance of sustainable energy and watergy alternatives, would result in added market investment in still more alternatives. The consumer receives enhanced payback for resources conserved and the producer avoids inefficient capital investment into expanded production and distribution capacity and corresponding emissions abatement. Again, Figure 7.1 shows that if a "three-year cost of abatement," or the equivalent cost to remove emissions from energy conserved by sustainable alternatives during a 3 year period, was internalized in the form of a capital cost subsidy, then all energy and watergy alternatives for all demographic groups would be selected in the south region. Due to regional market differences, a 7 year abatement subsidy would be required in both north and central regions to achieve similar results.

Conclusion

If these subsidies materialized by 2020, capital costs across the population could be reduced $2.9 billion, average CCR reduced by 25% to 2.6 years and average SIR increased by 30% to 5.8:1.0. Total NO_x, SO_2 and CO_2 emissions would be reduced an additional 1.9 x 10^9lbs, 1.3 x 10^9lbs, and 4.4 x 10^9 lbs per year respectively. Yet in spite of this potential for market-based emissions reduction, the Florida Department of Environmental Protection (DEP) has ignored its own scientific findings, citing that a consensus has not been reached on which "set of values is accurate or wholly defensible" (Table 7.7). As a condition for a sustainable society it must be understood that all of the infinite workings and interdependencies of the natural, social and economic system may never be empirically knowable. Yet, concepts based on reasonable assumptions, like those proposed herein, must begin to link economic activities to the environmental impacts they cause.

Table 7.7. Summary of Florida public utility commission's activities regarding externalities (23).

Current Status	Approach toward Incorporating Externalities	Rationale	Future
None	Florida Power Plant Sitting Board appointed task force to draft legislation on a DEP publication that stated externalities should be viewed in the power plant licensing process. The Florida legislature did not enact the legislation.	According to Florida's Department of Environmental Protection, use of quantitative values for environmental externalities is not practical now because there is no consensus that any set of values is accurate or wholly defensible.	The Florida Public Service Commission itself is not formally considering the issue. There are no dockets or rulemaking underway.

CHAPTER 8
SUMMARY AND CONCLUSIONS

A summary of research findings is presented herein including 1) a summary of research results, 2) opinions and recommendations, and 3) areas in need of further research. A summary of research results includes a synopsis on each of the major sections of this research highlighting significant findings that contribute to the research objectives. This research describes how to operationalize sustainable residential development by providing a methodology for assessing the market potential of "greening" technologies for typical new single-family housing in Florida. This dissertation determined the life-cycle ROI variance for several sustainable alternatives and compared this data to the consumer MARR (Chapters 4 and 5). The market elasticity for these alternatives was calculated and a decision matrix constructed to provide building professionals a reliable method for selecting sustainable alternatives that provide a meaningful contribution to consumer life-cycle cost savings (Chapter 6).

The spirit of this work, however, remains focused on the reduction of resource consumption by addressing the degradation of the environment proactively rather than reactively, meaning that as a result of quantifying the life-cycle ROI performance of sustainable alternatives and the consumers' willingness-to-pay for them, tools such as the decision analysis matrix can be developed to enable the construction industry to effectively market sustainable products that reduce resource use and its attendant emissions rather than to pursue mitigation strategies for pollutants resulting from continued inefficiencies. Consequently, the ecological impacts of using life-cycle cost models, market survey assessments, and decision analysis matrices as a market-based approach to promote the use of sustainable energy and watergy alternatives in new housing entering the dwelling stock in Florida from 2000-2020 were also addressed. A hypothetical look at point source energy and attendant air-emissions that could be potentially reduced or eliminated as a result of the market elasticity for sustainable energy and watergy alternatives was also included. Finally, a conceptual framework for energy and air-emission reductions possible as a result of cost of abatement subsides was presented (Chapter 7).

Summary of Research Results

Sustainable development as a "systems" response to global environmental degradation seeks a symbiotic relationship between economic prosperity and sustainable resource use by linking the products of economic development to market-driven sustainable processes. Pricing resources according to their life-cycle efficiencies and ecological impacts results in an economy that rewards the "greening" of the built environment and penalizes inefficient, unsustainable practices that would in time, undermine both the health of the economy and the environment from which all material wealth is ultimately derived. Development predicated on life-cycle costing begins to operationalize sustainability by providing market-based incentives for investment in more resource efficient alternatives. Return-on-investment is in fact due almost exclusively to added resource efficiency, where units of resources conserved are exchanged for units of monetary savings. Yet to determine the extent to which current markets exist for sustainable alternatives, the life-cycle ROI of each alternative was first modeled and the market response to each alternative was assessed.

Background

In addition to establishing a broad philosophical framework for the sustainability paradigm, the *Background* defined a theoretical role for a market-based approach that would link the activities of the economic system to the limits of sustainability defined by the natural system. The natural system incorporates endogenous growth in a way that is consistent with the laws of thermodynamics, which simply states that there are points at which efficiency is optimized and limits to growth maximized. Therefore, accounting for the life-cycle efficiency of a resource within the economic system is more reflective of the cradle-to-grave processes found in the natural system.

Sustainable construction. To model the market-based approach to sustainable development through the life-cycle cost-benefit and consumer response to "greening" alternatives, a researchable population, namely the construction industry, was selected among the leading U.S. GDP sectors. Construction contributes between 8-10% or in excess of $500 billion to the U.S. GDP annually, and from an environmental perspective, is more resource intensive than industries with higher GDP.

Sustainable residential construction. Of the estimated $585 billion put in place in 1997, more than third was relegated to residential construction alone, including more than 1,452,000 new housing starts. Of the more than $200 billion in residential construction, 80% was single-family detached housing. Corresponding to resource use, new single-family detached housing has increased in average "footprint" from 1,460sf in 1966, to more than 1,950sf in 1996.

Residential energy consumption and emissions to air. Reduced energy requirements equate to less finite resource withdrawal, ecosystems impact and energy related pollutants. Residential buildings account for roughly half of Florida's electrical energy use and are responsible for approximately $5 billion in annual energy expenditures.

Residential watergy consumption and aquifer draw-down. Seven densely populated regions of Florida represent 60% of the State's total population and nearly 70% of its domestic withdrawal. Use of potable water has increase by a factor of six in the last 90 years with 75% of this overdraft occurring in the last 25 years. 80% of Florida's 14 million people reside near the coast where shallow aquifers are most vulnerable to subsequent wastewater discharge and saltwater intrusion. In addition to the energy used to heat water for domestic purposes, as much as 4.0 kWh of treatment and distribution energy is embodied within every 1000 gallons of municipal water produced.

Residential owner-occupants. Owner-occupants are considered the most influential demographic of residential consumers since they have an investment incentive in both the capital cost and life-cycle return of the housing unit. Furthermore, more than 40% of the total dwelling stock in the U.S. is owner-occupied and more than 50% in Florida.

High-growth residential regions of north, central and south Florida. Of the State's 4.8 million residential structures and 7.3 billion square feet of habitable space, single family stock comprises 3.1 million structures (65%) and 4.7 billion square feet of usable space (64%). Of this, roughly 50% of both structures and habitable floor space is located within the immediate metropolitan areas of Jacksonville, Orlando and Miami, representing the major high-growth residential regions of north, central and south Florida as well as 44% of the State's population and more than 50% of its owner-occupants.

Methodology

To answer the primary research question "*to what extent will capital costs and life-cycle return-on-investment (ROI) affect consumer willingness-to-pay for sustainable energy and watergy alternatives,*" the following research objectives were established;

Objective I - Life-cycle cost modeling. Determine optimal energy and watergy alternatives based on maximum return-on-investment (ROI_{max}) at 5 year capital cost recovery (CCR) intervals.

Objective II - Market survey assessments. Determine the effect of life-cycle ROI on consumer response to sustainable energy and watergy alternatives.

Objective III - Decision analysis matrices. Develop a matrix to provide a predictive "tool" allowing building professionals to efficiently select marketable energy and watergy alternatives.

To develop and validate models and analyses necessary to execute the research objectives, a research population representing typical residential development in Florida was defined. Specific population parameters included:

- Single-family detached housing units (<2,500sf) constructed since 1990
- Sustainable energy and watergy alternatives within the building envelope of typical single-family detached dwelling stock.
- Owner-occupants of single-family detached housing units within high-growth residential regions in north, central and south Florida.

Once a researchable population was defined, a descriptive-correlational research design was developed to answer the stated research questions. As the primary contribution of the dissertation, this methodology was developed to address each of the three research objectives and included;

Life-Cycle Cost Modeling

The objective of this section was to provide a means to determine the variable cost-benefit of sustainable watergy alternatives under regional economic and environmental influences. Subsequently, a methodology was developed to down-select "optimal" ROI packages consisting of several energy and watergy alternatives. Since market survey data found that "optimal" ROI was defined differently among several consumer groups, various payback regimes were calculated in terms of capital cost recovery (CCR), savings-to-investment ratio (SIR), and total return-on-investment (ROI_{max}). Once completed, sustainable alternatives were selected according to their cost-benefit marketability to specific demographic groups in different regions using a decision analysis matrix. First however, a criteria was developed to segregate sustainable alternatives from conventional practices by the level of resource minimization provided. Two residential plan-forms typical of <2,500sf single-family detached housing constructed since 1990 in Florida were selected to model the performance and subsequent ROI of sustainable energy and watergy alternatives in each north, central and south region. Next, life-cycle cost models were developed, consisting of the following processes;

Independent performance simulation. Using the case study plan-forms, 1995 MEC compliant energy and watergy systems were added to provide a "conventional baseline" representative of newly constructed dwelling stock in high-growth Florida. The average annual energy and watergy load and consumption from each case study modeled in each region was determined. "Sustainable" alternatives to 1995 MEC compliant energy and watergy systems were then individually inserted into the baseline to note changes in unit load and consumption attributable to each alternative (i.e., Δ MBtu/1000sf/kHDD or Δ kWh/unit/kCDH).

Independent straight-line ROI. Having determined the added resource minimization performance of sustainable alternatives relative to the 1995 MEC baseline, the added capital cost for sustainable alternatives were then compared to the added benefits of life-cycle resource reduction. Since capital cost recovery (CCR), maximum return-on-investment (ROI_{max}), and savings-to-investment ratio (SIR) were found to contribute most to consumer willingness-to-pay, values for these variables were determined for each alternative using a straight-line LCA method. This procedure neglects the influences of inflation, resource cost escalation or the time-value of life-cycle costs and focuses instead on the simple payback of added energy and watergy savings relative to added "turn-key" construction costs.

Independent alternatives prioritization. Since two or more sustainable alternatives may be used in new single-family detached housing, and the performance and subsequent payback of two or more alternatives is less than the sum of their individual contributions as a function of declining marginal utility, a methodology was developed to select and "prioritize" energy and watergy alternatives that would provide optimal resource reduction and subsequent payback specific to select market demographics. As an example, the straight-line ROI data was used to categorize sustainable energy and watergy alternatives into 10, 15, 20 and 25 year CCR "packages." Each alternative was then prioritized by SIR. The result of this process was a listing of alternatives that would provide optimal CCR and SIR to the consumer, even if only a partial list of the alternatives were used due to limits on added capital costs. Depending on the desired forms of payback specific to different consumer groups, the models provide the flexibility to assemble packages and prioritize alternatives using any of the ROI_{max}, CCR, SIR or capital cost variables.

Integrated performance simulation. Once determining the appropriate variables to group and prioritize sustainable energy and watergy alternatives, the performance simulation is repeated with the exception of inserting cumulative sustainable alternatives into the baseline case-study by order of prioritization. A range and mean of performance values for each cumulative sustainable alternative was established from observed changes in overall case-study plan-form unit performance (Δ MMBtuh/yr, Δ 1000gal./yr, ect.), accounting for the declining utility of each added alternative. As an alternative to summating the individual performance of sustainable energy and watergy alternatives composing a given "package," a more realistic calculation of the resource load and consumption was determined by conducting and integrated performance simulation.

Integrated straight-line ROI. Having determined the integrated performance of several combinations of sustainable energy and watergy alternatives, the straight-line ROI method was repeated, accounting for the declining "payback" utility of each cumulative alternative. Although advanced amortization and time-value resource accounting remained absent, this process provided the "foundation" to model these and other net present value (NPV) variables in the method to follow.

Integrated amortization ROI. The integrated straight-line ROI method in the previous step was modified to account for the predicted effects of water and energy resource cost escalation, discounting, and inflation specific to each region. Changes in CCR, ROI_{max} and SIR for each sustainable energy and watergy alternative for each plan-form and region were calculated and presented as the NPV of total cost-benefit.

Results. Although single-family plan-forms vary widely and appreciable climatic differences exist between regions, research has shown that "unitizing" the performance of sustainable alternatives into metrics representing the physical characteristics of the structure and regional climate can produce order-of-magnitude values for resource savings and subsequent ROI per units of degree days and materials (i.e., MBtu/yr/100ft^2/CDD, kgal/yr/unit, etc.). These "average" slide-rule values were proven useful when screening alternatives for more comprehensive performance and ROI modeling. Research also identified a declining marginal utility function that had a significant effect on the performance and subsequent ROI of integrated energy alternatives as the total number of alternatives increased. Adding regional specific resource rates and capital cost structures with resource specific amortization and discounting to integrated energy and watergy "packages" resulted in the derivation of net present values (NPVs) for each alternative. Combined with market survey data, the NPV of energy and watergy alternatives were used to create a decision matrix, which allowed the selection of alternatives specific to regional demographic markets.

Market Survey Assessments

The objective of this section was to conduct a cross-sectional survey necessary to evaluate the extent to which capital costs and life-cycle return-on-investment affect consumer response to sustainable alternatives. The population of study for this research consisted of owner-occupied, single-family detached housing units stratified in high-growth residential regions of north, central and south Florida. Composed of the immediate metropolitan areas of Jacksonville, Orlando and Miami, this population represented 44% of Florida's 14.5 million population and approximately 50% of its residential owner-occupants.

Survey questions were developed to answer complex, intangible "willingness-to-pay" constructs by drawing direct and indirect inference from survey responses. Demographics were assessed to correlate significant differences in survey responses to consumer characteristics so that a decision matrix could be developed to "match" the ROI of select energy and watergy alternatives to consumer willingness-to-pay profiles where statistically significant relationships were found to exist ($\rho < 0.10$, $r \geq 0.70$).

For most interval scale data, the five-point Likert type scale was used, including a "neutral" response. For nomial scale demographic questions, such as *age* and *income*, respondents were given a range of values encompassing all relevant responses. Prior to pilot testing the completed survey draft, the instrument was distributed to the Doctoral Committee and then to the University of Florida Institutional Review Board (UFIRB). The UFIRB reviewed the survey instrument and rendered an approval to conduct the market survey assessment. Once UFIRB approval was obtained, the survey instrument was pilot tested using a random sample of approximately 25 respondents from the target sample frame. Using telecommunications as the data collection media, FRSC conducted the survey to 400 randomly selected respondents within the population. Results showed that the survey instrument produced valid and reliable data with a 95% confidence interval at +/- 5% error.

Results. Using market survey assessments, consumers were found to prioritize level of willingness-to-pay according to total return-on-investment, meaning willingness-to-pay changed proportional to changes in total return as that the vast majority of consumers chose high capital cost, high return alternatives. Results also indicated that the savings-to-investment (SIR) ratio was not as significant a consideration, meaning that if consumers viewed the purchase of a sustainable alternative as an "opportunity" cost, they should have chosen low cost, low return alternatives, which had the highest SIR, and invested the balance of their available resources elsewhere. As a result, the most fundamental discovery is that although incremental changes in capital costs, SIR and CCR are contributing factors, the variable most influencing consumer willingness-to-pay was clearly rate-of-return and subsequent ROI_{max}.

Although clear trends emerged between consumer willingness-to-pay and a) cost and non-cost issues, b) types of cost structures, 3) capital costs and life-cycle return, and d) demographics; consumer behavior remains a complex social phenomena that cannot be explained by a single critical factor, making attempts to determine causality with any degree of certainty very difficult without considerably more in-depth analysis. With this key limitation of research noted however, *Market Survey Assessments* provided the foundation to 1) correlate the affects of capital and life-cycle costs on consumer willingness-to-pay when other behavioral domains and consumer demographics are known, and 2) identify statistically significant differences in willingness-to-pay from norms and averages based on specific consumer profiles. With this information known, decision analysis matrices could be developed to "match" energy and watergy alternatives to specific consumer profiles in order to maximize market adaptation.

Decision Analysis Matrices

The decision analysis matrix was intended as a possible application of the research results from life-cycle cost modeling and market survey assessments. Although countless combinations of life-cycle cost factors and consumer demographics could be compared, only the cost variables most affecting the MARR of specific consumer groups were illustrated. Cost variables used to construct the matrices included CCR and SIR since rate-of-return, capital costs and ROI_{max} were found to have the most significant impact on consumer MARR. Among demographic variables, age and income were shown to have the most MARR variability.

To provide industry with a simple "score-card" that would allow building professionals to efficiently select sustainable energy and watergy alternatives based on level of market demand, the integrated and amortized performance of each alternative in each region was plotted within the domains of observed willingness-to-pay profiles from major consumer demographic groups. Specifically, the cost-benefit of sustainable alternatives were plotted as function of SIR and CCR, and then "overlain" by the willingness-to-pay domains of single demographic groups (i.e., age) and groups with multiple demographics (i.e., age and income). If the SIR and CCR performance of a sustainable alternative "fell" within the desired SIR and CCR domain of a given demographic group, then the alternative would be selected. A visual basic "screen" was also developed to provide a sample of what a computerized application of the decision matrix may later appear as.

Results. The development of the matrices and the "sample" software application demonstrates that a methodology could be developed to satisfy an industry need for a simple decision tool that would provide design-build professionals the ability to efficiently select marketable alternatives without cost intensive value-engineering analysis. Again, results indicated that significant relationships exist between consumer demographics and willingness-to-pay. By integrating the life-cycle cost modeling with market survey assessments, a methodology for predicting consumer willingness-to-pay was successfully demonstrated.

Eco-Economic Impacts

To link the eco-economic impacts of using sustainable alternatives, an internalization approach was used to quantify the cost of emissions abatement saved through conservation. This cost savings was then discounted from the capital cost of sustainable energy and watergy alternatives, based on the total energy conserved by the alternatives. The reduced capital costs of using this approach would be reflected as an increase in market efficiency and a decrease in pollution externalities.

Results. Based on an average 13 x 10^9 per month generation rate, predicted 1998 fossil-fueled power generation will account for no less than 1.56 x 10^{11} kilowatt hours. Of this, approximately half or 7.8 x 10^{10} kWh is consumed by the residential sector and at least 65% or 5.07 x 10^{10} kWh may be relegated to the singled-family dwelling stock. Fifty percent or more of the remaining energy, some 2.54 x 10^{10} kWh, may be appropriated by owner-occupied <2,500sf units in high-growth regions of north, central and south Florida. Based on an average of 7,500 kWh per single-family detached unit saved, the aggregate regions of north central and south Florida could reduce energy consumption as much as 1.4 x 10^{10} kWh, or 50% as a result of implementing sustainable energy and watergy alternatives.

Based on maximum market elasticity by 2020, results indicate that $840.2 million per year worth of *cost of abatement* emissions reductions are attainable through energy and watergy resource conservation, or the elimination of approximately 15 x 10^7 lbs of NO_x, 10 x 10^7 lbs of SO_2, and 23 x 10^9 lbs of CO_2. Depending on the number of alternatives selected specific to each demographic group in each region, the unsubsidized capital cost investment ranges from approximately $1,800 to $5,100 per capita. The NPV of annual "payback" ranges from $500 to $1,100 per capita, resulting in an average CCR of 3.5 years and a SIR of 4.4:1.0. From an aggregate population perspective, the projected 2.1 million owner-occupants in high-growth single-family detached housing by 2020 could realize an annual payback of $2.1 billion for a $7.3 billion capital investment.

Hypothetically, a 3-year cost of abatement would be necessary to reduce capital costs enough to stimulate willingness-to-pay for all energy and watergy alternatives in the 15 year CCR package for all demographic subsets in the south region. For the north and central regions, a 7-year cost of abatement would be necessary to reduce capital cost sufficiently to stimulate willingness-to-pay for all alternatives as a result of higher original capital costs and a lower NPV of conservation payback provided by these regions. If all of the sustainable energy and watergy alternatives in the 15 year CCR package were market implemented in the research population alone by 2020, capital costs could be reduced $2.9 billion, average CCR reduced by 25% to 2.6 years and average SIR increased by 30% to 5.8:1.0. Total NO_x, SO_2 and CO_2 emissions would be reduced an additional 1.9 x 10^7lbs, 1.3 x 10^7lbs, and 4.4 x 10^9 lbs per year respectively.

Conclusions and Recommendations

In spite of this potential for market-based emissions reduction, the Florida DEP has ignored its own scientific findings and succumbed to political pressures, citing that a census has not been reached on which "set of values is accurate or wholly defensible." As a condition for a sustainable society, one that begins to look beyond its individual rights and more toward its responsibilities to

generations unborn, we must understand that all of the infinite workings and interdependencies of the natural, social and economic system may never be empirically knowable. Qualitatively, it is undeniable that most of the earth's ecosystems are in decline, and the rate of decline is accelerating. To continue to obscure these truths behind the absence of equally compelling quantitative metrics is to justify continued resource devaluement and exploitation.

This research provides a methodology to *quantitatively* 1) assess the life-cycle cost-benefit of sustainable alternatives, 2) determine consumer willingness-to-pay for sustainable alternatives, 3) provide a basis for selecting alternatives specific to market demographics, and 4) assess the eco-economic impacts of sustainable alternatives by a) the reduced cost of emissions abatement, and b) the added market appeal of sustainable alternatives if the cost of emissions abatement is internalized (subtracted from capital costs). Although conceptual and limited in scope, this methodology provides quantitative metrics necessary to operationalize sustainable residential development through market-based structures and provides a foundation on which more comprehensive metrics can be built.

It is the conclusive opinion and recommendation of this work that the summarized results of this research be published and distributed within the residential building community in Florida to provide consumers building options that conserve energy and watergy resources for life-cycle cost savings. It is a secondary recommendation that the summarized results of this research be published and distributed among the various Federal, state, and local authorities so that legislation providing capital cost subsidies for sustainable products that promote public health and safety can be compensated for their externalized benefits to society.

Limitations and Recommendations for Further Research

This research provided, for the first time, a methodology to operationalize sustainable residential development by providing quantitative tools for assessing the market potential of "green" technologies in single-family housing. This research was however, theoretical in nature and limited in scope. The major weaknesses of this research rest first with the inability to determine the added performance and subsequent ROI of sustainable energy and watergy alternatives in relation to "baseline" 1995 MEC alternatives with respect to solar orientation and incidence.

The second major weakness of the research is found within the market survey assessments, which inferred desired payback structures such as CCR, SIR and ROI_{max} from respondent willingness-to-pay between several low, moderate and high capital cost, return-on-investment alternatives. Also, willingness-to-pay was taken out of its traditional context, meaning that for the purposes of this research, willingness-to-pay was considered the choice *between* several sustainable alternatives. Most often, willingness-to-pay means the choice between a sustainable and conventional alternative.

The third and perhaps most significant weakness remains in the inability of the decision analysis matrix to determine the willingness-to-pay weight and influence of all of the demographic subsets simultaneously. To accomplish this, a multiple regression and multivariate analysis would need to be run on all of the predictor variables to determine the level of influence of each in the decision process of the consumer. From this, much greater accuracy could be developed in selecting sustainable energy and watergy alternatives specific to consumer demographic profiles. A fourth and final limitation of this research to be discussed is the concept of internalizing the externalized cost of emissions abatement. Providing a capital cost subsidy to a sustainable energy or watergy alternative based on some fraction of its estimated stack pollution abatement potential over its useful life is but one internalization approach, and falls well short of accounting for the full costs of sustainable and unsustainable alternatives.

Topics for further doctoral research include developing a methodology to account for the embodied energy content of a building system, which may provide a more accurate indicator of cradle-to-grave resource efficiency, since a given amount of energy is invested in the harvesting, refining, transporting, use, reuse and eventual disposal of a building material. Another approach is to evaluate emissions, namely CO_2 , throughout the product life-cycle as either a surrogate for determining embodied energy or in concert with an embodied energy analysis to compare material "through-puts" and associated waste streams. CO_2 is among the primary thermal decomposition by-products of fossil fuel combustion, which results from the release of hydrogen from the hydrocarbons in fossil fuels, leaving the free carbon to recombine with available oxygen prevalent in the atmosphere.

Once the material, emissions, and energy invested in a material from cradle-to-grave are assessed, several other research methodologies could conceivably address the *full-cost* each of these life-cycle resource investments and by-product emissions. This process may be immeasurably more complex, since full-costing would have to account for such issues as costing renewable vs. non-renewable resources, opportunity costs, human health, ecosystems impacts, etc; which unlike the partial *hard-cost* methodology developed herein, have metrics of a qualitative nature that must be expressed as a quantitative cost.

Once a principally thermodynamic approach is defined for embodied resources and emission by-products, and an advanced economic methodology for pricing these full-cost material "through-puts" becomes defensible, a third tier of research must address methods for integrating these costs into a market economy. In spite of the many limitations of this research, the case seems clear that without internalizing the effects of eco-economic realities into the market place, the economy cannot be used as an instrument to insure resource consumption and waste discharge remains within the regenerative and assimilative capacity of a very finite natural system.

Yet, other "interim" methodologies may be developed that do not yet fully account for cradle-to-grave costing, but by comparison, are rather simplistic and can lead to appreciable near-term- gains in environmental protection. The development of policy structures such as "extended producer responsibility," could require the manufacturer to be a "steward" of the post consumer durable goods it produces. Rather than profit from current devalued energy and waste discharge pricing, the producer would be responsible for the recovery and reconstitution of post-consumer goods. Since waste discharge would no longer be an option and the cost of energy and energy related emissions would be market-prohibitive, an incentive would be created to produce goods of minimal inputs, and of those that are, durable, recyclable and low energy inputs would be most advantageous.

Yet these, and many other concepts, support the notion that in a market economy, market forces must be used to reward resource efficiency and penalize resource inefficiency. Only then can the true costs of natural system, from which all material wealth is ultimately derived, be accounted for and reflected within the economic and social system.

> "We treat nature like we treated workers a hundred years ago. We included then no cost for the health and social security of workers in our calculations, and today we include no cost for the health and security of nature" (82).

GLOSSARY

biodiversity The variety and variability among living organisms and the ecological complexes in which they occur.

Btu (British Thermal Unit) A standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

central tendency (measures of) Averages such as mean, mode and median commonly used to summarize the data in a frequency distribution.

chi-square (X^2) An inferential statistic that compares the frequencies of nominal measures actually observed in a study with frequencies expected under a null hypothesis.

chlorofluorocarbons (CFCs) A family of chemicals commonly used a refrigerants, solvents and aerosol propellants that drift into the upper atmosphere where their chlorine components destroy stratospheric ozone.

command and control An approach that attempts to control pollution by means of regulatory instruments.

construct An abstraction at a higher level than a concept used to explain, interpret and summarize observations and to form part of the conceptual content of a theory.

construct-related validity The degree to which an instrument measures the traits or characteristics implied by the construct it is intended to measure.

content-related validity The degree to which the items on an instrument representatively sample the underlying content domain.

correlation coefficient A statistic that shows the degree of relationship between two variables; value ranges between –1.00 and +1.00.

correlation matrix A table that shows the coefficients of correlation between every measure and every other measure.

cost-benefit analysis An economic tool for project evaluation or return-on-investment appaisal, cost-benefit analysis is used to quantify and compare the costs and benefits of alternative ways of achieving the same objectives.

cradle-to-grave or manifest system A procedure in which products of economic activity are quantitfied by the life-cycle embodied resources consumed and waste byproducts produced.

Cronbach alpha (α) An internal consistency reliability coefficient that measures the extent to which the scores of the individual items on a survey agree with one another. Used for attitude scales, Likert scales.

cross-sectional survey A survey in which data are collected at one point in time from a specified population.

cross-tabulation A table showing how frequently various combinations of two or more categorical (nominal) variables occur, from which one can "see" the relationship (if any) between the variables.

degrees of freedom (*df*) The number of observations free to vary around a constant parameter.

dependent variable A variable that is a consequence of or dependent on an independent variable.

descriptive research Research that asks questions about the nature, incidence or distribution of variables; involve description but not manipulation of variables.

ecosystem The interacting synergism of all living organisms in a particular environment; a complex web of interdependency.

effluent Wastewater, precipitate or production byproduct that flows out of a treatment plant, sewer or industrial outfall for most often surface disposal.

embodied energy Is the amount of energy contained in or invested in a material or product, including the extraction, manufacturing, transportation and installation of a material or product.

emission The release or discharge of a substance into the environment; generally refers to the release of gases or particulates into the air.

emissions trading As a hybrid command and control–market-based approach, an emission trading system is a regulatory environment where an overall emissions "cap" is established and market forces are left to allocate emissions in the most cost-effective manner under the cap. Emissions producers who exceed emissions standards may sell "credits" to producers who do not meet emissions standards.

extraneous variable An uncontrolled variable that may affect the dependent variable of a study; its effect may be mistakenly attributed to the independent variable of the study.

global warming The scientific hypothesis which states that the earth's temperature is rising as a result of the increasing concentration of certain gases, known as greenhouse gases, in the atmosphere, trapping heat that would otherwise radiate into space.

gross national product (GNP) The market value, in monetary terms, of goods and services produced by labor and property supplied by the residents of a nation, within a specified period of time.

independent variable A variable that is antecedent to the dependent variable.

inferential statistics Procedures that permit one to make tentative generalizations from sample data to the population from which the sample was drawn.

institutional review board (IRB) A committee that determines whether proposed research meets federal and other legal and ethical standards.

internalizing externalities The act of creating social and economic conditions where the damages (or benefits) from production and consumption are taken into account by those who produce these effects.

interval scale A scale of measurement that orders survey responses and has points equidistant from one another.

level of significance the largest probability of error acceptable for rejection of the null hypothesis; often $\rho = 0.05$.

Likert scale A measurement scale consisting of a series of statements followed by five response categories ranging from strongly agree to strongly disagree.

margin of error An estimate of the extent to which sample results are likely to deviate from the population value.

market pricing approach The market approach to internalizing externalities that attempts to place the costs of externalities directly in the marketplace, therefore causing the prices for products or services to reflect their full social and environmental costs.

mean A measure of central tendency for a distribution of interval scale; the sum of the scores divided by the number of scores in the distribution; the arithmetic average.

median The point in a distribution below which are 50 percent of the scores; used with ordinal or interval data.

mode The score that occurs most frequently in a distribution of scores; used with nominal, ordinal and interval data.

multiple regression The prediction of a criterion using two or more predictor variables in combination. Each predictor is weighted in proportion to its contribution to prediction accuracy. The equation showing the weights assigned to each predictor is the *multiple regression equation*.

nominal (categorical) scale A scale of measurment that classifies objects or individals into categories that are qualitatively but not quantitatively different.

particulates Solid particles, such as ash, released in exhaust gases at fossil fuel plants during the combustion process.

Pearson product moment coefficient (Pearson *r*) An index of correlation for interval or ratio data; it is the mean of paired *z*-score products of the two variables.

pilot study A trial run with a few subjects to assess the appropriateness and practicality of the procedures and data collecting instruments.

polychlorinated biphenyls (PCBs) A group of toxic, persistent chemicals used in electric transformers and capacitors for insulating purposes, new sale and use banned in 1979.

population The larger group to which a researcher wishes to generalize; includes *all* members of a defined class of people, events or objects.

probability sampling Sampling employing random selection, which means that every element in the population has a non-zero chance of being selected.

range A nominal measure of dispersion; the difference between the highest and lowest scores plus 1 unit of measure.

regression line The line of "best fit" for a set of scores plotted in a scattergram.

reliability The extent to which a measure yields consistent results; the extent to which scores are free of random error.

renewables An energy source that is regenerative or virtually inexhaustible. Typical examples are wind, geothermal, water and solar power.

sample A group selected from a population for observation in study.

standard deviation A measure of the extent to which individual scores deviate from the mean of the distribution; the square root of the variance; a measure of dispersion used with interval data.

standard error of measurement An index of the amount of measurement error in survey scores; theoretically, the standard deviation of the distribution of observed scores around an individual's true score.

standard error of the mean The standard deviation of sampling error of the mean; indicates how much the means of random samples drawn from a single population can be expected to differ through chance alone.

stratified sampling A probability sampling technique that first divides a population into subgroups by relevant variables such as age, social status, or education, and then randomly selects subjects from each subgroup.

subsidies Financial incentives, usually for reduced capital cost investment, that are employed to ensure the fulfillment of an environmental policy objective using market forces.

validity The extent to which a measure actually taps the underlying concepts that it purports to measure.

variability The dispersion or spread in a distribution of scores.

variance The mean of squared deviation scores; an interval measure of dispersion of scores around the mean.

***z*-score** A standard score that indicates how far a score is from the mean score in terms of standard deviation units.

APPENDIX I
SUSTAINABLE ALTERNATIVES DATABASE

Foreword

As a means to establish a sustainable criteria, identify sustainable energy and watergy alternatives, and determine optimal ROI, detailed life-cycle cost-benefit models were developed and case study tested in Chapter 4 to assess and integrate several interdependent energy and watergy alternatives into optimal ROI "packages" at 5 year intervals. The database of sustainable alternatives developed for ABACOA has been used as a basis to test the life-cycle cost-benefit models. The database herein contains only those energy and watergy alternatives from ABACOA that have been determined to have a meaningful impact on the life-cycle cost-benefit of the residential case studies selected to represent the target population.

The energy and watergy alternatives described herein have been selected based on their life-cycle contribution to resource minimization and subsequent reduced environmental impact. In general, the capital cost pricing, life-cycle performance and environmental impact assessment have been provided for each alternative.

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High Thermal Efficiency, Window Systems **CSI:08520**

To provide thermal insulated, recyclable, extended life-cycle, low maintenance windows for energy and material resource minimization.

This resource work item pertains to operable or fixed sash units. Available either in a mill finish or with colored finish. Thermally broken windows are highly recommended. Aluminum windows have gained a large share of the market in recent years because of their low operating cost. They are durable , do not need to be painted and are virtually maintenance free . However, aluminum frames have a low thermal efficiency and like any aluminum product, require enormous energy to produce. Double glazed windows help to insulate the interior environment from outside noise and temperature differences. A thermal break will substantially increase the performance of the window. Tinted glazing helps to limit excessive solar radiation but does not eliminate all the resultant heat gain. A much better solution is to use a Low-E coating on the glass. This coating reflects the majority of the low-energy radiant heat that strikes it. The aluminum frame can be easily recycled at the end of its usable life. The National Fenestration Rating Council (NFRC@(301) 589-6372*)*

Performance:

		U (Btu/hr*ft^2 *°F)	**SHGC** (Solar Heat Gain Coef.)
101.	SGL/LoE Metal	0.90	0.56
102.	SGL w/ Break Metal	1.09	0.73
103.	DBL/LoE/Vinyl	0.36	0.45
104.	TPL/Vinyl	0.36	0.52
105.	DBL/LoE Wood	0.39	0.46
106.	TRP/Wood	0.39	0.53
107.	DBL/Vinyl	0.46	0.57
108.	DBL/Wood	0.49	0.58
109.	DBL/LoE w/ Break Metal	0.53	0.52
110.	TRP w/Break Metal	0.53	0.60
111.	DBL w/ Break Metal	0.65	0.66
112.	DBL Metal	0.87	0.73

Capital Cost:

101.	SGL/LoE Metal	$ 7.80/sf.
102.	SGL w/ Break Metal	$ 6.43/sf.
103.	DBL/LoE/Vinyl	$10.60/sf.
104.	TPL/Vinyl	$14.78/sf.
105.	DBL/LoE Wood	$22.02/sf.
106.	TRP/Wood	$25.80/sf.
107.	DBL/Vinyl	$ 9.60/sf.
108.	DBL/Wood	$20.60/sf.
109.	DBL/LoE w/ Break Metal	$13.17/sf.
110.	TRP w/Break Metal	$14.45/sf.
111.	DBL w/ Break Metal	$11.55/sf.
112.	DBL Metal	$ 7.75/sf.

High Shade Coefficient Soffit Design **CSI: 08525**

To modify building soffit design to provide life-cycle energy resource minimization through reduced solar loading on walls and windows.

This design work item pertains to building soffit designs that reduce solar loading through the use of extended overhangs to provide enhanced shading coefficients to windows.

Performance:

Reduced solar radiant heat gain on exterior walls, depends on site orientation and latitutde.

120. 24in. Soffit
121. 36in. Soffit
122. 48in. Soffit

Capital Costs:

120.	24in. Soffit	$ 4.20/lf	(added cost)
121.	36in. Soffit	$ 8.35/lf.	
122.	48in. Soffit	$12.50/lf.	

Thermal Efficient Wall Insulation **CSI:07210**

To provide wall insulation to reduce conductive and convective heat transfer for reduced HVAC loads and subsequent energy resource minimization.

This resource work item pertains to wall air spaces that are filled with heat transfer resistive materials. The use of extruded polystyrene (XPS) is prohibited. Insulation materials manufactured utilizing CFC and HCFC blowing agents are prohibited. Insulation materials such as cellulose, and cotton insulation with low embodied energy, that are disposable, and that are manufactured using recycled materials are encouraged for use. All insulating materials shall be certified by the American Society of Testing Materials (ASTM).

Common Walls - Walls common to two separate space conditioned tenancies must be insulated to a value of R-11 for framed construction. A masonry wall in the same use must be insulated to a value of R-3 on both sides.

Exterior Walls - Wood frame 2"x 4" construction are required to be insulated to a value of R-13, while walls of 2"x 6" construction are required to be insulated to a value of R-19. Exterior masonry walls must have a R-5 to R-7 rating.

Performance:

		U-value
201.	R-19 Batt, R-5 Continuous	0.040
202.	R-19 Batt.	0.051
203.	R-13 Batt, R-5 Continuous	0.055
204.	R-11 Batt, R-5 Continuous	0.060
205.	R-13 Batt.	0.073

Capital Cost:

201.	R-19 fiberglass Batt, R-5 continuous expanded polystyrene	$0.40/sf.	(added cost)
202.	R-19 fiberglass Batt.	$0.22/sf.	
203.	R-13 fiberglass Batt, R-5 continuous expanded polystyrene	$0.20/sf.	
204.	R-11 fiberglass Batt, R-5 Continuous expanded polystyrene	$0.18/sf.	
205.	R-13 fiberglass Batt.	$0.03/sf.	

Thermal Efficient Ceiling Insulation — CSI:07220

To provide ceiling insulation to reduce conductive and convective heat transfer for reduced HVAC loads and subsequent energy resource minimization.

This resource work item pertains to ceiling air spaces that are filled with heat transfer resisitive materials. Insulation materials manufactured utilizing CFC and HCFC blowing agents are prohibited. Insulation materials such as cellulose, and cotton insulation with low embodied energy, that are disposable, and that are manufactured using recycled materials are encouraged for use. All insulating materials shall be certified by the American Society of Testing Materials (ASTM).

Common Ceilings An insulation level of at least R-19, space permitting. Exposed Deck and Beam Construction Insulation of R-10 is required. Common Ceiling/Floors Wood, steel and concrete ceilings/floors common to separate conditioned tenancies shall be insulated to a minimum R-11, space permitting.

Performance:

		U-value (flat plane)
301.	R-25 Ceiling Insulation, 8"	0.038
302.	R-30 Ceiling Insulation, 10"	0.032
303.	R-35 Ceiling Insulation, 12"	0.028
304.	R-38 Ceiling Insulation, 12"	0.026

Capital Cost:

301.	R-25 Ceiling Insulation	$0.09/sf.	(added cost)
302.	R-30 Ceiling Insulation	$0.15/sf.	
303.	R-35 Ceiling Insulation	$0.23/sf.	
304.	R-38 Ceiling Insulation	$0.26/sf.	

High Efficiency Split Residential HVAC Systems — CSI:15650

To provide non-ODC, high efficiency space conditioning for energy resource minimization and clean air compliance.

This system work item pertains to a direct expansion air conditioning unit with independent evaporator/air handler and condensing units with electric strip heat. A minimum SEER rating of 12.0 is required for the split system air conditioning unit. All other types of air conditioning units or heat pumps must have a SEER rating of 10.0 or greater. SEER 12 systems will reduce energy costs for cooling the home up to 20% over the federally mandated minimum standard of 10 SEER. The system must be certified by the Air Conditioning and Refrigeration Institute (ARI).

Capital Cost:

401.	7 HSPF/12 SEER ASHP HVAC Systems	$ 300.00/unit	(added cost)
402.	7 HSPF/14 SEER ASHP HVAC Systems	$ 550.00/unit	
403.	8 HSPF/16 SEER ASHP HVAC Systems	$1,500.00/unit	
404.	90 AFUE/12 SEER Gas/Straight HVAC Systems	$1,150.00/unit	
405.	90 AFUE/14 SEER Gas/Straight HVAC Systems	$1,400.00/unit	
406.	95 AFUE/16 SEER Gas/Straight HVAC Systems	$2,800.00/unit	

Digital Programmable Thermostat Systems — CSI:15931

To provide a programmable thermostat to balance required water heating and space conditioning loads with peak occupant demands for energy resource minimization.

This system work item pertains to an electronic control that gives the occupant the ability to preset temperatures for specific times of day. Each home shall be equipped with a digital programmable thermostat. The programmable thermostat must have seven day programming capbility with night time setback. Mercury-Magnetic thermostats are prohibited. When properly used, a programmable thermostat can significantly reduce the energy consumption of the home. The savings realized are dependent on the occupant's lifestyle. Digital programmable thermostats, such as White Rogers (Mfg. #1F80-51), Honeywell (Mfg. #T8131C1004), are readily available through local HVAC contractors and suppliers.

Capital Cost:

409.	Digital programmable thermostat	$125.00/unit.

High Efficiency Indoor Electric Lighting Systems — CSI:16552

To provide high efficiency, extended life-cycle indoor lighting for energy and material resource minimization.

This resource work item pertains to the source of electric inside light consisting of the bulb which converts energy to light by using an electric charge to produce an electric arc to illuminate a vacuum or gaseous medium. All hard-wired fixtures must use compact fluorescent lamps and high performance fluorescent fixtures (with enhanced color rendering) must be installed in bathrooms and kitchens. The only exception is for lighting connected to dimmer. Fluorescent lamps are up to five times as efficient as incandescent lamps because they waste very little energy as heat. All fluorescent lamps need ballast's to start the lamp and to regulate the flow of electric current to the lamp. To minimize landfill waste two piece CFL's are recommended.

Performance:

501.	Standard incandescent:	12-18 LPW
	Halogen:	16-19 LPW
	Fluorescent:	60-90 LPW
	Compact Fluorescent:	40-60 LPW
	Metal Halide or High Pressure Sodium:	75-150 LPW

Capital Cost:

501. Range from $10 to $15 per lamp or approximately $150-$170 added cost per home.

High Efficiency Water Heating Systems — CSI:15731

To provide high efficiency natural gas water heating for energy resource minimization.

This system work item pertains to an appliance that utilizes natural gas to heat water for potable domestic use. Natural gas fueled water heaters are required. If the ASHRAE rating is below 90, an insulation blanket is required. Gas water heaters are insulated storage tanks with burners or heating units at the bottom. When hot water is drawn off the top of the tank, a tube moves incoming cold water to the bottom for heating. A thermostat turns the burner on when it senses cold water. For safety purposes, the Blue Star Design Certification Seal from the American Gas Association Laboratories (AGAL) is required.

Performance:

502.	R-5 Blanket	
503.	Gas Instant	0.65EF
504.	Gas Tank, 40 gal.	0.56EF (0.76 Rec. EFF)

Capital Cost:

502.	R-5 Blanket	$ 7.00ea.	
503.	Gas Instant	$190.00ea.	(added cost)
504.	Gas Tank, 40 gal.	$390.00ea.	(added cost)

High Efficiency Solar Thermal Water Heating Systems — CSI:15732

To provide supplemental solar thermal water heating for energy resource minimization.

This system work item pertains to an appliance that captures energy from the sun to heat water for domestic use. A passive "thermosiphon" system must be utilized if a solar hot water heater is selected. Water in the passive solar energy water heater moves between the solar collector and the tank by thermosiphoning. Thermosiphon solar energy water heater functions based on the principal that hot water rises and the cold water, being heavier sinks in the collector. Passive "thermosiphon" systems operate without pumps or controls and have no moving parts requiring maintenance and replacement.

Performance of active solar systems varies widely between equipment and geographical location. Collector types can range from air-direct, air indirect, liquid direct, and liquid indirect. Common collector types include single or double glazings in either flat black or solar selective. Single glazed flat black collectors are the least expensive and are most cost effective in temperate to sub tropical climates with low heating degree days (HDDs) and high solar incidence, such as Florida. Other design factors influencing performance and capacity are collector orientation, collector surface area, collector angle of incidence with the sun (tilt) and storage volume. Solar Rating and Certification Corp. (S.R.C.C.) and the Florida Solar Energy Center.

Capital Cost:

505. $1500 per unit.

High Efficiency Natural Gas Clothes Dryer Systems **CSI:11632**

To provide high efficiency gas clothes dryer systems for energy resource minimization.

This resource work item pertains to an appliance used to dry clothing. Dryers must be powered by natural gas. A gas unit may save 69% of the cost of drying clothes compared to an electric unit. No environmental certification is needed. However, for safety purposes, the Blue Star Design Certification Seal from the American Gas Association Laboratories (AGAL) is required. Gas clothes dryers are readily available through local distributors and suppliers.

Performance:

506. 50-70% reduction in operating costs.

Capital Cost:

506. Approximately $60-$100 more than an electric dryer.

High Efficiency Natural Gas Range Systems **CSI:11420**

To provide high efficiency gas heating food preparation for energy resource minimization.

This resource work item pertains to a cooking appliance that is powered by natural gas. Gas powered ranges with electric ignition devices shall be used in all homes. Gas powered ranges can save up to 50% in energy costs when compared to electric ranges. No environmental certification is needed. However, for safety purposes, the Blue Star Design Certification Seal from the American Gas Association Laboratories(AGAL) is required. Gas powered ranges are readily available through local distributors and suppliers

Performance:

507. 50% reduction in operating costs.

Capital Cost:

507. Approximately $70-$105 more than electric powered ranges.

Low-Flow Toilet Fixture Systems **CSI: 15450**

To provide low-flow toiletry fixtures that promote resource minimization and reduce life-cycle cost potable water consumption and wastewater discharge fees.

This system work item pertains to a bowl-shaped plumbing fixture used in bathrooms for human waste removal. All toilets in home construction will have a maximum water consumption of 1.6 gallons per flush (gpf). Toilets selected which meet the performance standard of 1.6 gpf must utilize that volume efficiently. Gravity fed toilets may meet this standard, but "pressure assisted flushing" and "turbo-flush" toilets are considered more effective. Optional toilet types may incorporate technologies that reduce water consumption to as low as 0.5 gpf. Toilets are one of the largest water users in homes with up to 50% of interior residential water consumption being used for this purpose. Recent developments in plumbing codes mandate a maximum flush of 1.6 gallons and many standard models of this type are now available.

However, technologies, especially in gravity fed toilets, are not always developed to handle the reduced water volume efficiently, requiring additional flushes with each use. Flushing twice uses 3.2 gallons of water, making the code requirement of 1.6 gpf meaningless. Newer types that use hydraulics and other devices can produce flows as low as 0.5 gpf but at far higher cost than the nominal toilet. American Standard CADET EL PA toilet is a pressure-assisted 1.6 gpf standard sized toilet. The American Standard HYDRA is a gravity-flush 1.6 gpf toilet. As required by the fixture manufacturer and the latest edition of the Standard Plumbing Code with Town of Jupiter amdendments.

Performance:

601. Up to 2gpf reduction in domestic water consumption and wastewater discharge.

Capital Cost:

601.	1. Gerber ULTRA FLUSH:	Retail - $210.00
	2. Kohler WELLWORTH:	Retail - $265.00
	3. American Standard CADET:	Retail - $300.00
	4. American Standard HYDRA:	Retail - $130.00
	5. Briggs ABINGDON:	Retail - $75.00

Low-Flow Shower Fixture Systems — CSI: 15457

To provide low-flow shower fixtures that promote resource minimization and reduce life-cycle cost potable water consumption and wastewater discharge fees.

This system work item pertains to water distribution devices that create a variety of water patterns for reduced water requirements needed for adequate showering. All shower heads installed *will exceed* the Federal standard of 2.5 gallons per minute (gpm) at <80 psi, while maintaining the integrity of the shower pressure. Extra features, such as hand held models and push button shut off, should also be considered in the selection process as these features can contribute to reduced water consumption. Recent improvements in the plumbing codes have restricted the water flow of shower heads from as much as 8 gpm to a maximum of 2.5 gpm. A push button, or shut off feature, creates an easy way to pause the flow during the shower and turn it back on with temperature memory.

Performance:

602.
1. Alsons #672, 2.0 gpm.
2. Interbath #E26300, 2.3 gpm.
3. Resource Conservation INCREDIBLE HEAD ES-400P, ES-400B, 2.3 gpm.
4. Teledyne Water Pik SUPERSAVER, 2.2 gpm.

Capital Cost:

602.	1. Alsons #672	Retail - $11.90 ea.
	2. Interbath CLASSIC II:	Retail - $10.00 ea.
	3. INCREDIBLE HEAD:	Retail - $ 7.00 ea.
	4. Teledyne Water Pik SUPERSAVER	Retail - $10.00 ea.

Low-Flow Sink/Lavatory Aerator Fixture Systems — CSI: 15458

To provide low-flow aerators on sink, shower and lavatory fixtures that promote resource minimization and reduce life-cycle cost water consumption and wastewater discharge fees.

This system work item pertains to a device which restricts water flow and breaks up the water stream, thereby reducing the total amount of water flow. Used at the point of discharge in indoor faucets. Bathroom faucets shall use aerators that reduce the flow of water to a maximum of 1.5 gpm. Kitchen faucets shall use aerators that reduce the flow of water to a maximum of 2.5 gpm. Aerators are simple screens and washers which break up and reduce the flow of water, so that while the actual flow of water is less, the apparent amount of flow seems the same as in a non-aerated faucet. These devices are relatively inexpensive and easily installed on any standard faucet. Many standard residential faucets have aerators installed in them, removing any additional effort to upgrade the faucet. Moen kitchen faucets have pre-installed FLOW-RATOR aerators which limits flow to 2.2 gpm.

Performance:

603.
1. Bathroom aerator, 1.5 gpm.
2. Kitchen aerator, 2.5 gpm.

Capital Cost:

603.	1. Real Goods BATHROOM AERATOR:	Retail - $4.50
	2. Real Goods KITCHEN AERATOR:	Retail - $4.50

High Efficiency Low-Flow Clothes Washer Systems — CSI:11631

To provide high efficiency clothes washing through reduced hot water demand for energy and water resource minimization.

This resource work item pertains to a washer in which laundry is gently lifted and plunged into the water rather than being twisted and pulled by an agitator in a conventional washer. Horizontal axis washer must have a 45% reduction in water and energy use in a normal wash cycle (one wash and two deep rinses) for a 16-18-pound load of laundry. A typical vertical axis machine uses 40 gallons of water whereas a horizontal-axis machine uses only 21 gallons.

Performance:

604. 50% reduction in water use translates to a 50% energy savings when washing with hot or warm water.

Capital Cost:

604.	Staber Industries, Inc. System 2000 Model	$ 730 ea.
	Hydromatic-Novotronic Washing Machine	$ 2,345 ea.
	Creda, Inc. EcoWash CWA 242 series	$ 1,200 ea.

APPENDIX II
SUSTAINABLE ALTERNATIVES ROI PERFORMANCE MODELING

Foreword

The primary contribution this performance simulation provides beyond the current state-of-the-art in this field is 1) a detailed life-cycle performance and ROI cost integration of sustainable energy and watergy alternatives compared to conventional alternatives, 2) a performance simulation using actual climatic data points rather than factor of safety design parameters, and 3) a computational model and database of future ROI variance between energy and watergy alternatives based on realistic interest and discount rate amortization over a typical building life-cycle.

PERFORMANCE SIMULATION

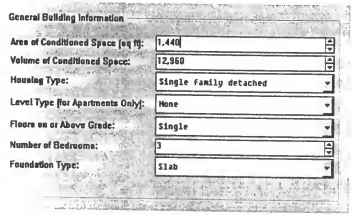


Figure A-1.1. General building information, *REMDesign*™

For each north, central and south region, conventional energy and water alternatives for both case study plan-forms "A" and "B" were modeled to establish a performance "baseline." Sustainable energy and watergy alternatives were then inserted individually into the "baseline" scenario for each plan-form in each region to assess the change in performance. The following is a sample of one complete energy and watergy performance simulation for plan-form "A" located in Jacksonville, Florida.

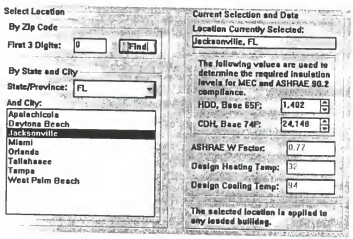


Figure A-1.2. Site HDD/CDD, *REMDesign*™

HDD & CDD Method. The degree day, a key variable used to compute conductive heat transfer over a given period, was originally developed to estimate seasonal space conditioning requirements. When the *daily average ambient temperature* is lower than the baseline 65°F, the numerical difference between the two is equal to the number of heating degree days (HDD). When the *daily average ambient temperature* is above the baseline 65°F, the numerical difference between the two is equal to the number of cooling degree days (CDD).

General Heat Transfer Concepts

All forms of energy, thermal or otherwise are expressed in consistent, interchangeable units. The most common unit for building energy analysis is Btu, which is equal to the amount of energy required to raise one pound of water 1oF at sea level. Energy moves by the process of heat transfer. Heat transfer processes are completely dependent on the physical properties of the materials involved in the process. To a greater extent than conventional alternatives, sustainable energy designs, systems, and resources typically are composed of or utilize materials that inhibit heat flow and the subsequent energy demands to add or remove heat for space conditioning.

The greater the temperature difference (ΔT) between conditioned spaces and ambient (outside), the greater the rate of heat transfer (30). Three modes of heat transfer exist, conduction, convection, and radiation. More thermally energetic bodies always attempt to release energy to less energetic bodies by some or all of these means. The relative rate at which heat is transferred through a solid object is referred to as a material's conductivity. Radiation refers primarily to the short-wave solar energy absorbed by building materials which elevates its temperatures in some cases to 100°F greater than the surrounding air temperature. The resulting ΔT may induce conductive heat transfer through building envelope media or long-wave IR radiation through a confined airspace, such as from roofing materials through the attic to the ceiling. In buildings, conduction and radiation are the primary means of heat transfer from ambient to the conditioned space through the thermal envelope (30).

Conduction Heating Loads

$Q = \Delta T/R$

$R = 1/U,\ U = 1/R_0$

therefore: $Q = U \times \Delta T$

where:
- Q = heat flux per unit area (Btu/hr ft^2)
- $\Delta T = t_H - t_L$, temperature difference (°F)
- R = thermal resistance (hr ft^2 °F/Btu)
- U = overall heat transfer coefficient (Btu/hr ft^2°F)

R values are usually used to express the resistance of single thickness homogeneous materials. In composite building envelopes where *series* connected heat flow paths of homogeneous materials compose a wall or roof section, the inverse of R-values may be added to obtain the overall heat transfer coefficient (U) of the envelope.

Ucomposite: $U = 1/(R_1 + R_2 + \ldots R_n)$

$Q = 1/R \times A \times \Delta T = U \times A \times \Delta T$

where:
- A = envelope surface area through which heat flows, ft^2
- $C = 1/R,\ C = k/L$

where:
- k = conductivity, Btu/hr ft^2°F per in. thickness
- L = thickness of material, in.

Conduction Cooling Loads

$Q = U \times A \times \Delta T_e$

$\Delta T_e = [(CLTD + LM) \times K + (78 - t_r) + (t_o - 85) \times f$

where:
- ΔT_e = corrected value for cooling
- CLTD = hourly correction factor for solar loads on roofs and walls, °F*
- LM = monthly correction factor for latitude*
- K = surface color correction factor (1.0 dark, 0.65-0.75 medium, 0.5 light)
- t_o = average outside temperature
- t_r = average room temperature
- f = ceiling ventilation correction factor (0.75 for attic fan, 1.0 other)

* *1985 Fundamentals, ASHRAE Handbook & Product Directory*

Roof, Attics and Ceilings

Gross Area

Determine the total ceiling/roof area, including skylights, which is in contact with either an attic or ambient conditions. If there is an attic, use the insulated ceiling area, not the roof area. To convert horizontal area to sloped ceiling area, multiply the horizontal area by the appropriate multiplier for the given ceiling pitch.

Table A-I.1. Ceiling pitch area multiplier, *REMDesign™*

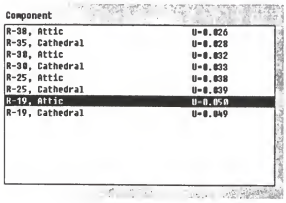
Ceiling Pitch	Area Multiplier
3/12	1.03
4/12	1.05
5/12	1.08
6/12	1.12
8/12	1.20
9/12	1.25
10/12	1.30
12/12	1.41

Exterior Color

Specify the color of the roof. Colors such as white or tan would be "light," colors such as black or dark brown would be "dark." Shake shingles are usually considered a "medium" color.

Radiant Barrier

Specify a radiant barrier only if the space between the radiant barrier and the roof decking is at least 2 inches. Radiant barriers are modeled as adding R-4.5 to the effective R-value of the roof in the cooling season, but not in the heating season.



Continuous Insulation R-Value

Determine the R-Value of insulation that is not interrupted by framing.

Cavity Insulation R-Value

Determine the R-Value of insulation that is interrupted by framing.

Cavity Insulation Thickness (in)

Determine the thickness of the framed insulation. This number is used to determine the R-Value of the wood framing for the parallel thermal path.

Figure A-I.3. U-values for ceiling types and insulation, *REMDesign™*

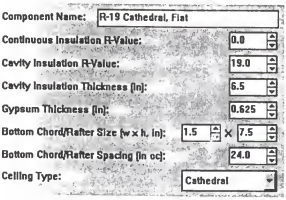

Component Name: R-19 Cathedral, Flat
Continuous Insulation R-Value: 0.0
Cavity Insulation R-Value: 19.0
Cavity Insulation Thickness [in]: 6.5
Gypsum Thickness [in]: 0.625
Bottom Chord/Rafter Size [w x h, in]: 1.5 x 7.5
Bottom Chord/Rafter Spacing [in oc]: 24.0
Ceiling Type: Cathedral

Figure A-I.4. Ceiling R-value calculation, *REMDesign™*

Gypsum Thickness (in)

Determine the thickness of the gypsum drywall used to finish the inside of the ceiling. Common thickness are 1/2 inch (0.5) and 5/8 inch (0.625).

Bottom Chord / Rafter Size (w x h, in)

Determine the width and height of the framing members. The width is used to determine the framing factor of the ceiling.

Bottom Chord / Rafter Spacing (in oc)

Determine the distance in inches between center lines of rafters or trusses.

Table A-I.2. Ceiling insulation R-value per type and thickness, *REMDesign*™

Description	R-Value/Inch
Fiberglass Batts	3.1
Blown Fiberglass	3.0
Blown Cellulose	3.3
Dense Fiberglass Batt	3.7
Dense Cellulose	3.7
Rock Wool Batt	3
Rock Wool Loose Fill	3
Vermiculite Fill	2

Table A-I.3. Nominal and actual R-values for compressed insulation, *REMDesign*™

Cavity	R-38	R-30	R-22	R-19
2x12	R-37			
2x10	R-32			
2x8	R-27	R-26		
2x6		R-21	R-20	R-18
2x4			R-14	R-13

Slab Floors

This section describes concrete slab floors of conditioned spaces, either slab on grade or conditioned basements. Do not include the floors of unconditioned basements or crawl spaces. Only specify exposed perimeter for slabs on grade. Heat loss for slabs below grade is dominated by heat loss through the floor rather than the perimeter. Specify the below grade masonry wall that abuts the slab below grade.

Area

Determine the total area of floors with the same depth and insulation levels. If the slab is partially abutted by conditioned space or a subfloor buffer space, enter an area which is the same fraction of the total area as the exposed perimeter is to the total perimeter. Determine a slab on grade separately from slabs below grade.

Full Perimeter

The full perimeter of the slab is used to properly estimate the geometry of the slab. The portion of the perimeter primarily responsible for heat loss is specified as the exposed perimeter.

Exposed Perimeter

This value is required only for slab floors on-grade to calculate heat loss from the exposed perimeter of slab floors. Determine the total length of slab edges exposed to ambient air, earth, or an outdoor space.

Depth Below Grade

Determine the depth from the top of the slab surface to grade. If the depth varies slightly due to gently sloping terrain, enter an average value. If the depth varies significantly, the slab should be entered in two sections, especially if any of it is at grade. Determine "0" for any slab on grade or less than 1 foot below grade.

Floor Edge Conductive Heat Loss

$$Q = E \times L \times \Delta T$$

where: E = edge heat loss coefficient, Btu/hr $ft^{2o}F$ per foot edge length
L = total length of outside (exposed) edges of floor, ft

Above-Grade Walls

This section describes above-grade frame, brick veneer, solid concrete, concrete block, stone, and brick walls.

Gross Area

Determine the total wall area, including windows and doors, using the exterior wall length and the interior floor-to-ceiling height. Exclude rim and band joist areas. In areas with dropped ceilings, measure the wall height as if the dropped ceiling were not present; i.e., from floor to main ceiling height. If brick wainscotting is present, measure to the exterior of the brick. In chimney areas, if there is frame wall between the conditioned space and outdoors, measure the wall area as if the chimney were not present.

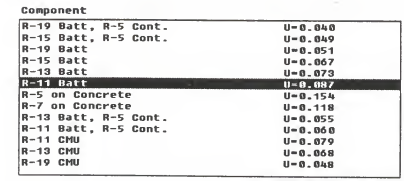


Figure A-I.5. U-values for select wall sections, *REMDesign*™

Exterior Color

Determine the exterior color of the wall. Colors such as white or tan can be considered as "light," colors such as dark brown should be considered "dark."

Continuous Insulation R-Value:

Determine the R-Value of insulation that is not interrupted by framing.

Frame Cavity Insulation R-Value:

Determine the R-Value of insulation that is interrupted by framing.

Cavity Insulation Thickness (in):

Determine the thickness of the framed insulation. This number is used to determine the R-Value of the wood framing for the parallel thermal path, and if there is an air gap between the insulation and the drywall.

Stud Size (w x d, in)

Determine the width and depth of the framing members. The width is used to determine the framing factor of the wall and the depth is used in conjunction with the cavity insulation thickness to determine if there is an air gap between the insulation and the drywall.

Stud Spacing (in oc)

Determine the distance in inches between center lines of studs. Common values are 16 and 24 inches on center.

Gypsum Thickness (in)

Determine the thickness of the gypsum drywall used to finish the inside of the wall. Common thickness are 1/2 inch and 5/8 inch (0.625).

Block Cavity R-Value

This input will only be enabled if the wall type Hollow Core Concrete Block is chosen. Determine the R-Value of any insulating material inside the block cavity.

Doors

This section describes opaque door areas.

Table A-I.4. R-values of select door types, *REMDesign*™

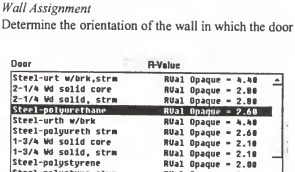
Door	R-Value
1-3/4" insulated steel door	R-4.4
2-1/4" solid core wood door	R-2.8
1-3/4" solid core wood door	R-2.1
1-3/8" solid core wood door	R-1.7
1-3/8" hollow core wood door	R-1.3
1-3/4" wood panel wood door	R-1.3
1-3/8" wood panel wood door	R-0.9

Opaque Area

Determine the total net opaque door area for all doors with the same R-value. If the door has an adjacent side panel of similar construction, include its area as part of the door area. If the door has glazing, deduct the glazed area from the total door area and compute as window.

Wall Assignment

Determine the orientation of the wall in which the door is located.


Door
R-Value
Steel-urt w/brk,strm RUal Opaque = 4.48
2-1/4 Wd solid core RUal Opaque = 2.88
2-1/4 Wd solid, strm RUal Opaque = 2.88
Steel-polyurethane RUal Opaque = 2.60
Steel-urth w/brk RUal Opaque = 4.48
Steel-polyureth strm RUal Opaque = 2.60
1-3/4 Wd solid core RUal Opaque = 2.10
1-3/4 Wd solid, strm RUal Opaque = 2.10
Steel-polystyrene RUal Opaque = 2.08
Steel-polystyre strm RUal Opaque = 2.08
Steel-fiberboard RUal Opaque = 1.88
Steel-fiberbrd strm RUal Opaque = 1.88
Steel-urethane foam RUal Opaque = 1.78

R-Value of Opaque Area

Determine the R-value of the door. Common values are shown below. When a storm door is present, the door R-value is increased by R-1.

Figure A-I.6. R-value of opaque door area, *REMDesign*™

Table A-I.5. U-values for glazed doors and skylights, *REMDesign*™

Doors and Skylights	Metal without Thermal Break	Metal with Thermal Break	Metal-Clad Wood	Wood or Vinyl
Single Pane Door	1.26	1.10	0.99	0.98
Single Pane Skylight	1.92	1.93	1.50	1.47
Double Pane Door	0.80	0.66	0.57	0.56
Double Pane Skylight	1.30	1.13	0.88	0.85

Table A-I.6. U-values for non-glazed doors and storm doors, *REMDesign*™

Non-Glazed Doors	Foam Core- No Storm	Solid Core- With Storm
Steel Door (1-3/4" thkn)	0.35	0.60
Wood Door (1-3/4" thkn):	-	-
Panel with 7/16" panels	0.54	0.36
Hollowcore Flush	0.48	0.32
Panel with 7/16" panels	0.39	0.28
Solid Core Flush	0.40	0.26

Windows

This section describes the glazings in vertical walls and the glazed portions of doors. Radiant energy from the sun passes through transparent materials such as glass and becomes a heat gain source. The heat gain value varies with time, orientation, shading, and storage effect (interior mass).

Solar radiation

$$Q = SHGF \times A \times SC \times CLF$$

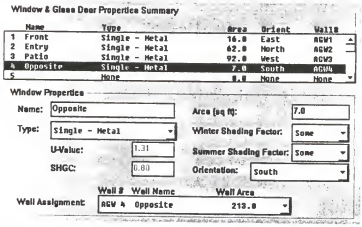
where:

Q = solar heat gain through glass, Btuh

$SHGF$ = maximum solar heat gain factor, Btuh/ft^2*

SC = shading coefficient*

CLF = cooling load factor for glass*



U-Value

The U-value is in Btu/hr/F/sf for the entire window assembly, not the center of glass. This value should be based on the testing procedures of the NFRC.

SHGC

The Solar Heat Gain Coefficient is for the entire window assembly. This value should be based on the testing procedures of the NFRC.

Figure A-I.7. Glazing load calculations with respect to orientation, *REMDesign*™

Area

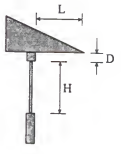
Determine the rough opening area. Measure to the nearest inch. Add together the areas of all similar windows facing the same direction (within 45 degrees) with the same wall orientation.

Summer and Winter Shading Factor

These entries define the degree to which windows are shaded, thereby reducing the amount of solar heat gain transmitted through them. Shade can be provided by blinds and curtains on the inside of windows, insect and solar screens on the outside, overhangs and wing walls which are part of the building's shape and form, trees and shrubs which may seasonally lose and gain foliage, and nearby buildings and land forms. The shading values are in the range from 0 to 1. For a totally unshaded window the shading factor is 1.0. A window with a value of 0.0 would be completely shaded from all direct and diffuse sunlight. In general, winter shading factors are greater than summer values. The shading factor accounts for blockage of sunlight only. The difficulty in determining shading factors increases as the number of devices providing the shade increases. The "complete shade" value is not zero because diffuse and reflected radiation still enter the window. Shading factors provided by venetian blinds and roller shades can range from 0.25 to 0.7, depending on the color of the shades and the degree which they are open. Similarly, shading factors from draperies range from 0.15 to 0.8, depending on the reflectance and transmittance of the fabric.

Table A-I.7. Overhang shading classifications, *REMDesign*™

Type	Geometry
None	2D >= L
Some	(D + H) >= L > 2D
Most	2(D + H) >= L > (D + H)
Complete	L >= 2 (D + H)



Interior Mass

This input section describes thermal mass elements located within the building interior which increase the building's overall thermal capacity. Include only mass which is not covered by material which acts as insulation, (e.g. carpeting).

Area

Determine the total mass area exposed to the air inside the building. If both sides of a mass element are exposed to the room air, include the total area of both sides. Do not include finished surfaces (e.g., walls which have been furred out and drywalled).

Location

Determine the proper mass location. Sunlit floors receive direct sun through most of the heating season. To be considered a sunlit floor, the floor must also be as dark or darker than unpainted concrete; that is, the absorptivity must be greater than 0.6. Shaded floors do not receive any direct sun. Massive walls need not be directly sunlit or dark in color; however, they must be in rooms that receive appreciable sunlight during the heating season. Because massive walls and floors may also provide a thermal benefit during the cooling season, be sure to enter all massive walls or floors that are shaded or located in remote (not sunlit) rooms.

Thickness

Determine the thickness perpendicular to the mass surface. If the area of both surfaces is included in the previous input, divide the thickness in half (i.e., consider it as two mass surfaces with half the thickness of the original mass component).

Air Infiltration & Exfiltration

This section determines the building's natural and mechanical air leakage. Two types of infiltration values are allowed: estimated values based on observable or proposed design characteristics (user estimate and checklist estimate), and measured values (tracer gas or fan depressurization blower door results). Data requirements vary for each and are described below. The minimum allowable checklist estimate value is 0.4 air changes per hour (ACH). MEC compliance requires verification of infiltration rates below 0.67 ACH.

Whole House Infiltration Values

You may enter different values for the heating and cooling seasons if desired. This is probably only appropriate when specifying natural ACH. The units for the infiltration rate can be selected to the right of the infiltration values. The whole house infiltration rate should include natural infiltration from duct leakage.

Duct Leakage

Specifying duct leakage adds heating and cooling load due to pressurized leakage during furnace or air-conditioner run time. Natural infiltration due to duct leakage is calculated from the whole-house infiltration values, which should include duct leaks. The load added to the heating and/or cooling equipment from duct leakage will depend on the leakage rates and the location of the ducts. Only leakage occurring in ducts outside the thermal shell of the building should be included. Duct leakage is largely a function of heating or cooling equipment run time. Run time depends on equipment size. If you have not measured duct leakage you should allow REM to calculate duct leakage from whole-house infiltration. If you have measured duct leakage using blower door subtraction or duct pressurization, enter either the total duct leakage, or separate values for supply and returns, only including the ducts outside conditioned spaces..

Mechanical Ventilation Rate

Mechanical ventilation refers to a ventilation system designed to continually bring outdoor air into the house to maintain indoor air quality. The Mechanical Ventilation Rate refers to the ventilation rate of the mechanical ventilation system (in cubic feet per minute or CFM), separate from the basic heating or cooling equipment. The mechanical ventilation system is assumed to operate continuously during the heating season. During the cooling season, the mechanical ventilation system is on only during periods of mechanical cooling by air conditioning or by an evaporative cooler.

Mechanical Ventilation Type
Supply and Return or Exhaust Only. Supply and Return indicates air is both supplied to and removed from the space. This makes heat recovery possible via an air to air heat exchanger. Because adding and removing air in the same quantities do not change any of the house pressures, supply and return mechanical ventilation and the infiltration values are additive. Exhaust only infiltration, in contrast, does not allow heat recovery, and does change the house pressures. The interaction of exhaust only ventilation and infiltration is defined in ASHRAE Fundamentals:

Maximum (Exhaust, Natural Infiltration + 0.5 Exhaust)

Heat Recovery Efficiency
Determine the heat recovery efficiency of the mechanical ventilation system. This is the efficiency with which heat is transferred between the supply and exhaust air streams of the mechanical ventilation system. This value applies during the heating and cooling seasons. Only sensible heat exchange is assumed. No heat recovery is assumed for exhaust only systems. A 100 indicates that all of the heat is recovered, and a 50, that half of the heat is recovered.

Sills
The typical leakage area is the joint between the masonry foundation wall and the wooden mud sill which sits on top of it. Also look at the joints between the sill and the rim joist, and the rim joist and the floor above.

Penetrations
This sub-section describes penetrations through the building envelope caused by doors, windows, patio doors, trim, and mechanical/electrical penetrations. For each input in this section, choose the dominant case observed in the home. Use the following criteria to determine how to classify weather stripping (w.s.) for door, window, and patio door seals. (High quality weather stripping only applies to doors.)

Window Type and Seal
This sub-section refers to leakage around the window sash, i.e., the seal which operates as the window is closed. Leakage associated with the window frame and trim is covered separately in the Trim Seal entry below. Use the following criteria to choose window type and seal:

Patio Door Type and Seal
Sliding patio doors can have large quantities of air leakage around their perimeter. Hinged patio doors with compression seals tend to be much tighter.

Trim Seal
This input refers to door and window trim, baseboards, trim where different materials meet (e.g., around fireplaces), and so on. Joints hidden by this trim present many paths for air movement and leakage. It is tough to seal trim effectively and comprehensively. Check a variety of locations, including inside closet trim.

Mechanical/Electrical Penetration Seal
This sub-section refers to the many penetrations through partitions and framing for electrical, plumbing, gas lines, and duct work, including the following:

Heating Equipment
This sub-section describes the condition of the space heating system, the water heater as they influence the infiltration rate. Conventional combustion space and water heating systems exhaust heated house air both when the unit is operating and when it is not. The problem is reduced if the unit is located in unconditioned space or if it uses outside air as in a sealed combustion system. Power vent systems also partially mitigate the problem by blocking the stack when the system is not operating.

To determine the sensible heat loss of the infiltration air, it is necessary to convert mass units of lb/hr and specific heat of air to equivalent mass flow rates in CFM (ft^3/min) for heat loss due to outside air infiltration.

$$Q_s = 1.1 \times CFM \times \Delta T$$

where: Q_s = sensible heat required for infiltration and ventilation (Btu/hr)
CFM = air infiltration rate (ft^3/min)

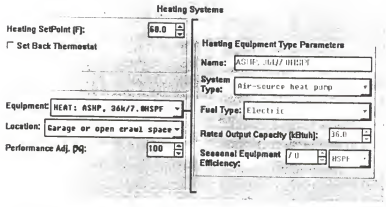
Since infiltration air is often less humid than room air, moisture must be added requiring latent heat of water vaporization to maintain comfort levels.

$$Q_L = 0.68 \times CFM \times (W_H - W_L)$$

where: Q_L = latent heat required for infiltration and ventilation (Btu/hr)
$W_H - W_L$ = higher (inside) and lower (outside) humidity ratio (gr w/lb d.a.)

Heating System

This input section describes the characteristics of the heating system. The heating system for a building can be described by one or multiple pieces of heating equipment.



Heating Setpoint
Choose a heating setpoint in the range of 60 to 75F.

Set Back Thermostat
Determine if there is a programmable thermostat with setback present.

Location:
Determine the location of the heating system. Calculate internal gain from the heating equipment.

Figure A-I.8. Heating system performance calculations, *REMDesign*™

Performance Efficiency Adjustment
Determine the performance efficiency as a percent of the nominal efficiency. A performance efficiency of 100% means the equipment is operating at nominal rating. Over time equipment efficiency declines, requiring cleaning and other maintenance.

Fuel Type
Choose the proper fuel type. The fuel type must be consistent with the system type.

Rated Output Capacity
Take this value from the heating system nameplate (typical values are 30 to 150 kBtuh). Be sure to take the output, not the input, value. For electric systems, convert kW to kBtuh by multiplying by 3.413. For heat pumps, specify the rated capacity at 47F. This value influences the duct loss calculations, since the system capacity affects the total run time. Oversized systems will have less duct losses than undersized systems due to differences in run times.

Table A-I.8. Seasonal equipment efficiency, *REMDesign™*

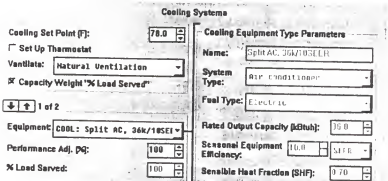
Efficiency Units	Conversion factor
COP	= AFUE / 100
COP	= HSPF / 3.413
AFUE	= HSPF / 0.03413
AFUE	= COP x 100
HSPF	= AFUE x 0.3413
HSPF	= COP x 3.413

Determine the seasonal heating plant efficiency, as measured using DOE standard methods. For equipment installed in 1982 or later, look up the rated efficiency value listed in the Gas Appliance Manufacturers Association (GAMA) Consumers Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment or for heat pumps the Air-Conditioning and Refrigeration Institute (ARI) directories. For furnaces or boilers record the AFUE. For air-source heat pumps record the HPF. For ground-source heat pumps record the average annual COP. This value will be different than the COP values listed in the ARI directory. Ground-source heat pump performance will vary depending on local weather and the installation of the unit.

Heating - HSPF
Determine the Heating Season Performance Factor for the piece of equipment you are entering.

Heating - Capacity at 47F
Take this value from the heating system nameplate (typical values are 30 to 150 kBtuh). Be sure to take the output, not the input, value. Convert kW to kBtuh by multiplying by 3.413. This value influences the duct loss calculations, since the system capacity affects the total run time. Oversized systems will have less duct losses than undersized systems due to differences in run times.

Cooling System
This section describes the characteristics of the cooling system. The cooling system for a building can be described by one or multiple pieces of cooling equipment. If you do not have mechanical cooling equipment, you do not need to enter any values in this input section.



Cooling Setpoint
Specify a cooling setpoint in the range of 70 to 85F.

Set Up Thermostat
Determine if there is a programmable thermostat with set abilities present. The set schedule assumes a 3 degree offset from 9am to 3pm.

Figure A-I.9. Cooling system performance calculations, *REMDesign™*

Whole House Ventilation
Determine the type of ventilation that occurs or is most likely to occur. "Natural" ventilation uses windows to strategically cool the home when outside conditions are favorable. We suggest this setting as users typically open their windows and doors during such conditions.

Performance Efficiency Adjustment
Determine the performance efficiency as a percent of the nominal efficiency. A performance efficiency of 100% means the equipment is operating at nominal rating. Over time equipment efficiency declines, requiring cleaning and other maintenance.

Cooling - SEER
Determine the Seasonal Energy Efficiency Ratio for the piece of equipment you are specifying.
Cooling - Capacity
Determine the nameplate value for the capacity of the cooling equipment in kBtuh (one ton of cooling equals 12 kBtuh). Make sure you specify the output, not the input. This value influences the duct loss calculations, since the system capacity affects the total run time. Oversized systems will have less duct losses than undersized systems due to differences in run times.

Cooling SHF
Determine the manufacturer's specified value for sensible heat fraction (SHF). This number will have a value less than 1. SHF is a measure of what fraction of an air conditioner's total capacity is available to remove sensible heat from the air. The remaining capacity is available for the removal of moisture from the air (latent heat). This is important to know for selecting cooling equipment in humid regions, so that the air can be both cooled and dehumidified. Generally, the higher the efficiency, the higher the SHF. (Most high efficiency air conditioners do not do a good job of dehumidification.) Typical values for SHF range from 0.5 to 1.0.
Suggested default efficiencies for heating, cooling, and water heating equipment are listed below. If values are unavailable from equipment nameplates, it is suggested that values from the Gas Appliance Manufacturers Association (GAMA) Consumers Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment or the Air-Conditioning and Refrigeration Institute (ARI) directories be used.

Table A-I.9. Typical MEC efficient HVAC by year of manufacture, *REMDesign*™

	Units	Pre-60	60-70	70-74	75-83	84-87	88-91	92-94	96-
Heating Equipment									
Gas Furnace	AFUE	60	60	65	65	68	76	78	80+
Oil Furnace	AFUE	60	65	72	75	80	80	80	80+
ASHP	HSPF	4.5	4.5	4.7	5.5	6.3	6.8	6.8	7.0+
GSHP	COP	2.7	2.7	2.7	3.0	3.1	3.2	3.5	3.5+
Cooling Equipment									
ASHP	SEER	5.0	6.1	6.5	7.4	8.7	9.4	10.0	12.0+
GSHP	EER	10.0	10.0	10.0	13.0	13.0	14.0	16.0	16.0+
Central AC	SEER	5.0	6.1	6.5	7.4	8.7	9.4	10.0	12.0+
Room AC	EER	5.0	6.1	6.1	6.7	7.7	8.1	8.5	9.0+

Ducts
This input section describes heating and cooling supply ducts. Ducts within conditioned space may be included, but they have no impact on heating and cooling loads. Different entries should be used for supply and return ducts.

Type
Specify whether the duct is a supply duct or return duct. This input is used to estimate the temperature of the air moving through the ducts, and to establish the location of the return ducts for modeling duct leakage.

Area
Separate entries are necessary for ducts in different locations, ducts with different insulation levels, and supply and return ducts. To determine area, multiply the duct length (in feet) by its perimeter (in feet). If it is impossible to determine the duct size, assume a perimeter of 3 ft. A good assumption for duct area is 24% of the conditioned floor area for single-story homes and 16% for multi-story homes, two thirds of which would be supply, and one third return.

Duct Insulation

Determine the R-value of the duct insulation, if any. If ducts travel through unheated spaces (i.e., attics, crawlspaces, etc) heat transfer from the duct to the surrounding cooler spaces will result in significant heat losses. The table shows recommended values expressed as percents to be factored and added into the overall building heating load to account for duct losses. For most residential construction in temperate climates a duct loss correction factor of 10%-15% of the total building load should be added. Duct area approximation for single-story detached residential unit is 24% of total conditioned floor area, approximately 2/3 supply, 1/3 return as follows:

Plan-form A: 0.24(1,440sf) = 346sf; 231sf supply duct, 115sf return duct

Duct area approximation for two-story detached residential unit is 16% of total conditioned floor area, approximately 2/3 supply, 1/3 return as follows:

Plan-form B: 0.16(1,700sf) = 272sf; 181sf supply duct, 91sf return duct

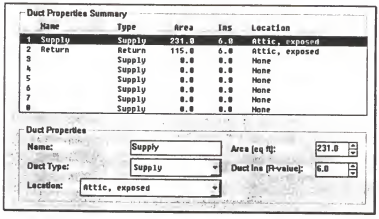
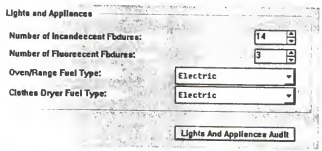


Figure A-I.10. Duct loss calculations, *REMDesign*™

Lighting and Appliances

This section describes the energy consumption of, and internal gains due to permanently installed appliances (e.g., the oven/range and the clothes dryer), and lighting fixtures. The reduction of energy use caused by permanently installed efficient lights and appliances can affect the home's analysis. However, because internal gains from efficient lights and appliances are generally less than for conventional lights and appliances, heating energy consumption may increase and cooling energy consumption may decrease. Thus, the net affect and impact on the home's analysis may be negligible.



Incandescent Fixtures

Determine the number of incandescent lighting fixtures that will be permanently installed inside the building envelope. This, with the Number of Fluorescent Fixtures, below, is used to determine the percentage of incandescent lighting.

Figure A-I.11. Lighting fixture consumption and cooling load, *REMDesign*™

Fluorescent Fixtures

Determine the number of fluorescent lighting fixtures that will be permanently installed inside the building envelope. This, with the Number of Incandescent Fixtures, above, is used to determine the percentage of incandescent lighting.

Lighting Heat Loads: $Q = 3.4 \times W \times BF \times CLF$

where: Q = net heat gain from lighting, Btuh
W = lighting capacity, watts
BF = ballast factor*
CLF = cooling load factor for lighting*

Domestic Hot Water (DHW) Heating

This section is used to describe the water heating system. Active solar systems used for water heating are described in the active solar system input screen.

Location

Choose the proper location. This value is used to account for heat loss to conditioned or buffer spaces.

Energy Factor

Determine the seasonal efficiency of the water heater, as measured using DOE standard methods. Typical efficiencies are between 0.40 and 0.90, except for heat pump water heaters for which the value can exceed 1.0.

Recovery Efficiency

For convential and integrated water heater types: look up the "Recovery Efficiency" listed in the Gas Appliance Manufacturers Association (GAMA) Consumers Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment. The recovery efficiency will be greater than or equal to the energy factor. It describes how efficiently energy is transferred to the water when the burner is firing. The Recovery Efficiency for convential electric systems are all assumed to be 0.98.

Water Tank Size

Determine water tank size in gallons.

Table A-I.10. HVAC efficiency trends, *REMDesign*™

	Units	Pre-60	60-69	70-74	75-83	84-87	88-91	92-96
Gas Storage	EF	0.47	0.47	0.47	0.49	0.55	0.56	0.56
Oil Storage	EF	0.47	0.47	0.47	0.48	0.49	0.54	0.56
Electric	EF	0.79	0.80	0.80	0.81	0.83	0.87	0.91

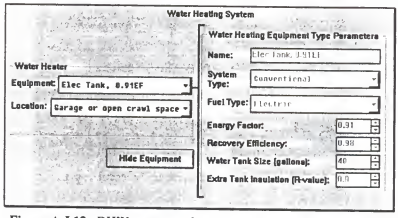


Figure A-I.12. DHW system performance calculations, *REMDesign*™

Table A-II.11 Windows and insulation, heating load, Δ MBtu/100ft²/yr/kHDD.

	Jacksonville Planform A	Orlando Planform A	Miami Planform A	Jacksonville Planform B	Orlando Planform B	Miami Planform B	RANGE		Average	
	Heating Load	Heating Load	Heating Load	Heating Load	Heating Load	Heating Load	Minimum	Maximum	Average	Deviation
SGL/LoE Metal Windows	0.52387	0.59921	n/a	0.50193	0.61728	n/a	0.50193	0.61728	0.56057	0.10289
SGL w/ Break Metal Windows	0.52387	0.51361	n/a	0.50193	0.50505	n/a	0.50193	0.52387	0.51111	0.02146
DBL/LoE/ARG Vinyl Windows	2.29696	2.48245	n/a	2.19263	2.35690	n/a	2.19263	2.48245	2.33224	0.06213
DBL/LoE Vinyl Windows	2.21637	2.39685	n/a	2.11338	2.30079	n/a	2.11338	2.39685	2.25685	0.06280
DBL/LoE/ARG Wood Windows	2.21637	2.39685	n/a	2.11338	2.30079	n/a	2.11338	2.39685	2.25685	0.06280
TRP Vinyl Windows	2.33726	2.56805	n/a	2.21905	2.35690	n/a	2.21905	2.56805	2.37032	0.07362
DBL/LoE Wood Windows	2.13577	2.31125	n/a	2.03413	2.24467	n/a	2.03413	2.31125	2.18145	0.06352
TRP Wood Windows	2.25666	2.48245	n/a	2.13980	2.30079	n/a	2.13980	2.48245	2.29493	0.07465
DBL Vinyl Windows	2.13577	2.31125	n/a	2.00771	2.13244	n/a	2.00771	2.31125	2.14679	0.07069
DBL Wood Windows	2.05518	2.22565	n/a	1.92846	2.02020	n/a	1.92846	2.22565	2.05737	0.07222
DBL/LoE/ARG w/ Break Windows	1.89399	2.05444	n/a	1.82279	1.96409	n/a	1.82279	2.05444	1.93383	0.05989
DBL/LoE w/ Break Windows	1.81339	1.96884	n/a	1.74354	1.90797	n/a	1.74354	1.96884	1.85844	0.06062
TRP w/ Break Metal Windows	1.97458	2.14004	n/a	1.84921	1.96409	n/a	1.84921	2.14004	1.98198	0.07337
DBL w/ Break Metal Windows	1.73279	1.79764	n/a	1.61145	1.62738	n/a	1.61145	1.79764	1.69232	0.05501
DBL Metal Windows	1.20893	1.19842	n/a	1.10953	1.12233	n/a	1.10953	1.20893	1.15980	0.04285
24in. Soffit Design	0.00000	0.00000	n/a	0.00000	0.00000	n/a	0.00000	0.00000	0.00000	0.00000
36in. Soffit Design	-0.19079	-0.18706	n/a	-0.12802	-0.11655	n/a	-0.19079	-0.11655	-0.15560	-0.23856
48in. Soffit Design	-0.31921	-0.35073	n/a	-0.21947	-0.17483	n/a	-0.35073	-0.17483	-0.26606	-0.33058
R-19 Batt, R-5 Cont., 2x6 Frame	0.10441	0.10506	n/a	0.10028	0.09620	n/a	0.09620	0.10506	0.10149	0.04363
R-19 Batt, 2x6 Frame	0.08243	0.08171	n/a	0.07763	0.07559	n/a	0.07559	0.08243	0.07934	0.04311
R-13 Batt, R-5 Cont., 2x4 Frame	0.07144	0.07004	n/a	0.07116	0.06871	n/a	0.06871	0.07144	0.07034	0.01935
R-11 Batt, R-5 Cont., 2x4 Frame	0.06045	0.05836	n/a	0.05823	0.05497	n/a	0.05497	0.06045	0.05800	0.04720
R-13 Batt, 2x4 Frame	0.03297	0.02335	n/a	0.02911	0.02749	n/a	0.02335	0.03297	0.02823	0.17048
R-7 Cont., CMU	0.07693	0.09338	n/a	0.07763	0.08246	n/a	0.07693	0.09338	0.08260	0.09959
R-25, 8" Ceiling	0.01981	0.01052	n/a	0.00699	0.00000	n/a	0.00000	0.01981	0.00933	1.06157
R-30, 10" Ceiling	0.02972	0.02104	n/a	0.02098	0.00000	n/a	0.00000	0.02972	0.01794	0.82851
R-35, 12" Ceiling	0.03963	0.03157	n/a	0.02098	0.00000	n/a	0.00000	0.03963	0.02304	0.85984
R-38, 12" Ceiling	0.04458	0.04209	n/a	0.02098	0.00000	n/a	0.00000	0.04458	0.02691	0.82826

Table A-II.12 Windows and insulation, heating consumption, Δ MBtu/100ft^2/yr/kHDD.

	Jacksonville Planform A	Orlando Planform A	Miami Planform A	Jacksonville Planform B	Orlando Planform B	Miami Planform B	RANGE			
	Heating Consumption	Heating Consumption	Heating Consumption	Heating Consumption	Heating Consumption	Heating Consumption	Minimum	Maximum	Average	Average Deviation
SGL/LoE Metal Windows	0.24179	0.25681	n/a	0.23776	0.28058	n/a	0.23776	0.28058	0.25423	0.08423
SGL w/ Break Metal Windows	0.24179	0.25681	n/a	0.23776	0.28058	n/a	0.23776	0.28058	0.25423	0.08423
DBL/LoE/ARG Vinyl Windows	1.08803	1.28403	n/a	1.05669	1.17845	n/a	1.05669	1.28403	1.15180	0.09869
DBL/LoE Vinyl Windows	1.04774	1.19842	n/a	1.03027	1.12233	n/a	1.03027	1.19842	1.09969	0.07645
DBL/LoE/ARG Wood Windows	1.04774	1.19842	n/a	1.03027	1.12233	n/a	1.03027	1.19842	1.09969	0.07645
TRP Vinyl Windows	1.12833	1.28403	n/a	1.08311	1.12233	n/a	1.08311	1.28403	1.15445	0.08702
DBL/LoE Wood Windows	1.00744	1.19842	n/a	1.00386	1.06622	n/a	1.00386	1.19842	1.06898	0.09101
TRP Wood Windows	1.08803	1.19842	n/a	1.05669	1.12233	n/a	1.05669	1.19842	1.11637	0.06348
DBL Vinyl Windows	1.00744	1.11282	n/a	0.97744	1.01010	n/a	0.97744	1.11282	1.02695	0.06592
DBL Wood Windows	0.96714	1.11282	n/a	0.95102	1.01010	n/a	0.95102	1.11282	1.01027	0.08008
DBL/LoE/ARG w/ Break Windows	0.92684	1.02722	n/a	0.89819	0.95398	n/a	0.89819	1.02722	0.95156	0.06780
DBL/LoE w/ Break Windows	0.88655	1.02722	n/a	0.84535	0.89787	n/a	0.84535	1.02722	0.91425	0.09946
TRP w/ Break Metal Windows	0.92684	1.02722	n/a	0.89819	0.95398	n/a	0.89819	1.02722	0.95156	0.06780
DBL w/ Break Metal Windows	0.80595	0.94162	n/a	0.79252	0.78563	n/a	0.78563	0.94162	0.83143	0.09381
DBL Metal Windows	0.56417	0.59921	n/a	0.52835	0.56117	n/a	0.52835	0.59921	0.56322	0.06291
24in. Soffit Design	0.00000	0.00000	n/a	0.00000	0.00000	n/a	0.00000	0.00000	0.00000	0.00000
36in. Soffit Design	-0.10273	-0.09353	n/a	-0.07316	-0.03885	n/a	-0.10273	-0.03885	-0.07707	-0.41447
48in. Soffit Design	-0.16511	-0.16367	n/a	-0.10973	-0.08741	n/a	-0.16511	-0.08741	-0.13148	-0.29546
R-19 Batt, R-5 Cont., 2x6 Frame	0.04946	0.05836	n/a	0.04852	0.04810	n/a	0.04810	0.05836	0.05111	0.10042
R-19 Batt, 2x6 Frame	0.03847	0.03502	n/a	0.03882	0.03436	n/a	0.03436	0.03882	0.03666	0.06082
R-13 Batt, R-5 Cont., 2x4 Frame	0.03297	0.03502	n/a	0.03558	0.03436	n/a	0.03297	0.03558	0.03448	0.03787
R-11 Batt, R-5 Cont., 2x4 Frame	0.02748	0.03502	n/a	0.02911	0.02749	n/a	0.02748	0.03502	0.02977	0.12668
R-13 Batt, 2x4 Frame	0.01099	0.01167	n/a	0.01294	0.01374	n/a	0.01099	0.01374	0.01234	0.11157
R-7 Cont., CMU	0.03847	0.03502	n/a	0.03882	0.04123	n/a	0.03502	0.04123	0.03838	0.08089
R-25, 8" Ceiling	0.00495	0.01052	n/a	0.00699	0.00000	n/a	0.00000	0.01052	0.00562	0.93661
R-30, 10" Ceiling	0.01486	0.01052	n/a	0.00699	0.00000	n/a	0.00000	0.01486	0.00809	0.91799
R-35, 12" Ceiling	0.01486	0.02104	n/a	0.01399	0.00000	n/a	0.00000	0.02104	0.01247	0.84362
R-38, 12" Ceiling	0.01981	0.02104	n/a	0.01399	0.00000	n/a	0.00000	0.02104	0.01371	0.76743

Table A-II.13. Windows and insulation, cooling load, Δ MBtu/100ft^2/yr/kCDH.

	Jacksonville Planform A	Orlando Planform A	Miami Planform A	Jacksonville Planform B	Orlando Planform B	Miami Planform B				
	Cooling Load	Cooling Load	Cooling Load	Cooling Load	Cooling Load	Cooling Load	Minimum	Maximum	Average	Average Deviation
SGL/LoE Metal Windows	0.11698	0.10639	0.11328	0.11810	0.10353	0.11280	0.10353	0.11810	0.11185	0.06512
SGL w/ Break Metal Windows	0.04679	0.03990	0.04302	0.04755	0.04032	0.04418	0.03990	0.04755	0.04363	0.08766
DBL/LoE/ARG Vinyl Windows	0.23396	0.20115	0.21939	0.23313	0.20161	0.21996	0.20115	0.23396	0.21820	0.07518
DBL/LoE Vinyl Windows	0.23396	0.20115	0.21939	0.23160	0.20161	0.21996	0.20115	0.23396	0.21795	0.07527
DBL/LoE/ARG Wood Windows	0.23396	0.20115	0.21939	0.23160	0.20161	0.21996	0.20115	0.23396	0.21795	0.07527
TRP Vinyl Windows	0.18717	0.16125	0.17494	0.18865	0.16129	0.17578	0.16125	0.18865	0.17485	0.07835
DBL/LoE Wood Windows	0.22694	0.19616	0.21365	0.22546	0.19508	0.21338	0.19508	0.22694	0.21178	0.07524
TRP Wood Windows	0.18015	0.15460	0.16920	0.18098	0.15475	0.17014	0.15460	0.18098	0.16831	0.07836
DBL Vinyl Windows	0.15442	0.13133	0.14339	0.15491	0.13187	0.14476	0.13133	0.15491	0.14345	0.08219
DBL Wood Windows	0.14740	0.12634	0.13765	0.14877	0.12642	0.13818	0.12634	0.14877	0.13746	0.08159
DBL/LoE/ARG w/ Break Windows	0.18717	0.16125	0.17494	0.18712	0.16129	0.17578	0.16125	0.18717	0.17459	0.07422
DBL/LoE w/ Break Windows	0.18717	0.16125	0.17637	0.18558	0.16129	0.17578	0.16125	0.18717	0.17457	0.07422
TRP w/ Break Metal Windows	0.13570	0.11471	0.12475	0.13650	0.11443	0.12596	0.11443	0.13650	0.12534	0.08806
DBL w/ Break Metal Windows	0.09592	0.07980	0.08747	0.09663	0.08065	0.08836	0.07980	0.09663	0.08814	0.09548
DBL Metal Windows	0.04913	0.03990	0.04302	0.05061	0.04032	0.04418	0.03990	0.05061	0.04453	0.12033
24in. Soffit Design	0.08308	0.07810	0.08303	0.07327	0.06677	0.07224	0.06677	0.08308	0.07608	0.10717
36in. Soffit Design	0.11248	0.10474	0.10967	0.09769	0.08827	0.09696	0.08827	0.11248	0.10164	0.11906
48in. Soffit Design	0.12717	0.11670	0.12455	0.10990	0.09959	0.10884	0.09959	0.12717	0.11446	0.12049
R-19 Batt, R-5 Cont., 2x6 Frame	0.00383	0.00204	0.00215	0.00413	0.00227	0.00265	0.00204	0.00413	0.00284	0.36763
R-19 Batt, 2x6 Frame	0.00287	0.00159	0.00156	0.00319	0.00173	0.00207	0.00156	0.00319	0.00217	0.37517
R-13 Batt, R-5 Cont., 2x4 Frame	0.00255	0.00136	0.00156	0.00282	0.00160	0.00184	0.00136	0.00282	0.00196	0.37240
R-11 Batt, R-5 Cont., 2x4 Frame	0.00223	0.00113	0.00117	0.00244	0.00147	0.00161	0.00113	0.00244	0.00168	0.39004
R-13 Batt, 2x4 Frame	0.00096	0.00045	0.00059	0.00113	0.00067	0.00081	0.00045	0.00113	0.00077	0.43951
R-7 Cont., CMU	0.00287	0.00136	0.00176	0.00282	0.00187	0.00196	0.00136	0.00287	0.00211	0.35886
R-25, 8" Ceiling	0.00259	0.00143	0.00159	0.00203	0.00115	0.00149	0.00115	0.00259	0.00171	0.41850
R-30, 10" Ceiling	0.00403	0.00245	0.00247	0.00365	0.00202	0.00224	0.00202	0.00403	0.00281	0.35711
R-35, 12" Ceiling	0.00518	0.00327	0.00300	0.00447	0.00260	0.00274	0.00260	0.00518	0.00354	0.36440
R-38, 12" Ceiling	0.00604	0.00368	0.00353	0.00447	0.00288	0.00299	0.00288	0.00604	0.00393	0.40134

Table A-II.14. Windows and insulation, cooling consumption, Δ MBtu/100ft^2/yr/kCDH.

	Jacksonville Planform A	Orlando Planform A	Miami Planform A	Jacksonville Planform B	Orlando Planform B	Miami Planform B				
	Cooling Consumption	Cooling Consumption	Cooling Consumption	Cooling Consumption	Cooling Consumption	Cooling Consumption	Minimum	Maximum	Average	Average Deviation
SGL/LoE Metal Windows	0.03977	0.03657	0.04158	0.03834	0.03487	0.03854	0.03487	0.04158	0.03828	0.08763
SGL w/ Break Metal Windows	0.01638	0.01330	0.01864	0.01534	0.01417	0.01504	0.01330	0.01864	0.01548	0.17256
DBL/LoE/ARG Vinyl Windows	0.07955	0.06816	0.07743	0.07822	0.06866	0.07426	0.06816	0.07955	0.07438	0.07655
DBL/LoE Vinyl Windows	0.07955	0.06816	0.07886	0.07822	0.06866	0.07426	0.06816	0.07955	0.07462	0.07631
DBL/LoE/ARG Wood Windows	0.07955	0.06816	0.07886	0.07822	0.06866	0.07426	0.06816	0.07955	0.07462	0.07631
TRP Vinyl Windows	0.06317	0.05486	0.06309	0.06288	0.05449	0.06016	0.05449	0.06317	0.05978	0.07260
DBL/LoE Wood Windows	0.07721	0.06650	0.07600	0.07669	0.06648	0.07238	0.06648	0.07721	0.07254	0.07395
TRP Wood Windows	0.06083	0.05320	0.06022	0.06135	0.05340	0.05734	0.05320	0.06135	0.05772	0.07062
DBL Vinyl Windows	0.05147	0.04489	0.05162	0.05215	0.04468	0.04888	0.04468	0.05215	0.04895	0.07626
DBL Wood Windows	0.04913	0.04322	0.05019	0.04908	0.04359	0.04700	0.04322	0.05019	0.04704	0.07403
DBL/LoE/ARG w/ Break Windows	0.06317	0.05486	0.06309	0.06288	0.05449	0.06016	0.05449	0.06317	0.05978	0.07260
DBL/LoE w/ Break Windows	0.06317	0.05486	0.06309	0.06288	0.05449	0.06016	0.05449	0.06317	0.05978	0.07260
TRP w/ Break Metal Windows	0.04445	0.03824	0.04588	0.04601	0.03923	0.04230	0.03824	0.04601	0.04269	0.09109
DBL w/ Break Metal Windows	0.03275	0.02660	0.03298	0.03221	0.02725	0.03008	0.02660	0.03298	0.03031	0.10526
DBL Metal Windows	0.01638	0.01330	0.01721	0.01534	0.01417	0.01504	0.01330	0.01721	0.01524	0.12822
24in. Soffit Design	0.02812	0.02634	0.02977	0.02389	0.02263	0.02440	0.02263	0.02977	0.02586	0.13791
36in. Soffit Design	0.03834	0.03572	0.03864	0.03292	0.03018	0.03254	0.03018	0.03864	0.03472	0.12189
48in. Soffit Design	0.04346	0.03996	0.04348	0.03743	0.03395	0.03709	0.03395	0.04348	0.03923	0.12139
R-19 Batt, R-5 Cont., 2x6 Frame	0.00128	0.00068	0.00117	0.00131	0.00080	0.00081	0.00068	0.00131	0.00101	0.31464
R-19 Batt, 2x6 Frame	0.00096	0.00045	0.00098	0.00094	0.00067	0.00069	0.00045	0.00098	0.00078	0.33571
R-13 Batt, R-5 Cont., 2x4 Frame	0.00064	0.00045	0.00098	0.00075	0.00053	0.00058	0.00045	0.00098	0.00065	0.40025
R-11 Batt, R-5 Cont., 2x4 Frame	0.00064	0.00045	0.00078	0.00075	0.00053	0.00046	0.00045	0.00078	0.00060	0.27251
R-13 Batt, 2x4 Frame	0.00032	0.00023	0.00059	0.00038	0.00027	0.00023	0.00023	0.00059	0.00033	0.53850
R-7 Cont., CMU	0.00096	0.00045	0.00059	0.00094	0.00067	0.00069	0.00045	0.00096	0.00072	0.35193
R-25, 8" Ceiling	0.00086	0.00041	0.00088	0.00041	0.00029	0.00025	0.00025	0.00088	0.00052	0.61283
R-30, 10" Ceiling	0.00144	0.00082	0.00123	0.00081	0.00087	0.00075	0.00075	0.00144	0.00099	0.35080
R-35, 12" Ceiling	0.00173	0.00102	0.00141	0.00122	0.00087	0.00100	0.00087	0.00173	0.00121	0.35657
R-38, 12" Ceiling	0.00201	0.00123	0.00159	0.00122	0.00087	0.00124	0.00087	0.00201	0.00136	0.42229

Table A-II.15. Lighting, DHW and appliances, total load and consumption , Δ MBtu/ea/yr

Description	Jacksonville Planform A Total Load	Orlando Planform A Total Load	Miami Planform A Total Load	Jacksonville Planform B Total Load	Orlando Planform B Total Load	Miami Planform B Total Load	Minimum	Maximum	Average	Average Deviation
Indoor Compact Fluorescent	0.02857	0.02143	0.04286	0.02353	0.03529	0.03529	0.02143	0.04286	0.03116	0.34382
Electric Water Heat, R-5 Insulation	0.30000	0.30000	0.20000	0.40000	0.30000	0.30000	0.20000	0.40000	0.30000	0.33333
Gas Instant Water Heat	5.20000	5.00000	4.70000	5.20000	5.00000	4.70000	4.70000	5.20000	4.96667	0.05034
Gas Water Heat, R-5 Insulation	1.50000	1.40000	1.30000	1.50000	1.40000	1.30000	1.30000	1.50000	1.40000	0.07143
Solar Water Heat	12.50000	12.10000	10.60000	13.00000	12.40000	11.60000	10.60000	13.00000	12.03333	0.09972
Natural Gas Clothes Dryer	1.20000	1.10000	2.30000	0.00000	0.00000	0.00000	0.00000	2.30000	0.76667	1.50000
Natural Gas Range-Oven	0.90000	2.00000	3.80000	0.00000	0.00000	1.80000	0.00000	3.80000	1.41667	1.34118
High Efficiency Refrigerator	0.50000	0.70000	1.20000	0.00000	0.00000	1.20000	0.00000	1.20000	0.60000	1.00000

Description	Jacksonville Planform A Total Consumption	Orlando Planform A Total Consumption	Miami Planform A Total Consumption	Jacksonville Planform B Total Consumption	Orlando Planform B Total Consumption	Miami Planform B Total Consumption	Minimum	Maximum	Average	Average Deviation
Indoor Compact Fluorescent	0.07143	0.08571	0.07857	0.12353	0.11765	0.12353	0.07143	0.12353	0.10007	0.26032
Electric Water Heat, R-5 Insulation	0.30000	0.30000	0.30000	0.40000	0.30000	0.30000	0.30000	0.40000	0.31667	0.15789
Gas Instant Water Heat	4.20000	4.00000	3.90000	4.20000	4.00000	3.90000	3.90000	4.20000	4.03333	0.03719
Gas Water Heat, R-5 Insulation	1.90000	1.80000	1.70000	2.00000	1.80000	1.70000	1.70000	2.00000	1.81667	0.08257
Solar Water Heat	13.20000	12.50000	11.60000	13.30000	12.60000	11.90000	11.60000	13.30000	12.51667	0.06791
Natural Gas Clothes Dryer	3.80000	7.60000	6.50000	2.40000	2.40000	2.40000	2.40000	7.60000	4.18333	0.62151
Natural Gas Range-Oven	3.30000	3.30000	3.70000	2.30000	2.50000	2.80000	2.30000	3.70000	2.98333	0.23464
High Efficiency Refrigerator	1.60000	1.60000	1.90000	1.60000	1.60000	1.80000	1.60000	1.90000	1.68333	0.08911

Table A-II.16. Watergy total consumption (Δ MBtu/ea/yr, Δ 1000gal/ea/yr; assume 4 persons/household, no regional difference)

	Energy, Δ MBtu/ea/yr				Water, Δ 1000gal/ea/yr			
Description	Minimum	Maximum	Average	Average Deviation	Minimum	Maximum	Average	Average Deviation
Low-Flow Toilet Fixtures	0.000	0.000	0.0000	0.0000	8.000	10.000	9.0000	0.1111
Low-Flow Shower Fixtures	1.428	1.679	1.5536	0.0807	4.400	5.200	4.8000	0.0833
Low-Flow Sink and Lavatory Aerators	0.105	0.139	0.1220	0.1223	1.000	1.100	1.0500	0.0476
Low-Flow Clothes Washer	0.680	0.731	0.6905	0.0417	4.950	5.650	5.3000	0.0645
Low-Flow Dish Washer	3.060	3.179	3.1195	0.0187	4.250	4.750	4.5000	0.0556

STRIAGHT-LINE ROI SIMULATION

The following return-on-investment simulation summarizes the change (Δ) in heating, cooling and total costs of sustainable energy and watergy alternatives when compared to 1995 MEC compliant alternatives. The values in tables A-II.19. – A-II.x. represent the energy and water cost savings provided by each alternative as simulated in plan-forms A and B in the climatic regions of Jacksonville, Orlando, and Miami. Return-on-investment calculations have been standardized to provide an *average* change in capital costs, annual rate of return, break-even point, and maximum return-on-investment from the respective regions.

Table A-II.17. Residential electric combined rates and fees, $/kWh.

City-Region	Base	Rank	City	Rank	County	Rank
Jacksonville - North Region	$0.07	1	$0.08	1	$0.08	1
Orlando - Central Region	$0.08	5	$0.09	5	$0.09	4
Miami - South Region	$0.08	7	$0.09	7	$0.09	7
Average	$0.08	n/a	$0.09	n/a	$0.09	n/a
Total Average	$0.09					

Table A-II.18. Residential natural gas combined rates and fees, $/therm (100kBtu).

City-Region	Base	Rank	City	Rank	County	Rank
Jacksonville - North Region	$1.05	4	$1.15	5	$1.15	4
Orlando – Central Region	$0.95	2	$1.00	3	$1.00	2
Miami – South Region	$0.00	n/a	$0.00	n/a	$0.00	n/a
Average	$1.00	n/a	$1.10	n/a	$1.10	n/a
Total Average	$1.07					

Table A-II.19. Residential potable and wastewater combined rates and fees, $/1000 gal.

City-Region	Base	Rank	City	Rank	County	Rank
Jacksonville – North Region	$6.60	n/a	$6.85	n/a	$6.85	n/a
Orlando – Central Region	$6.35	n/a	$6.50	n/a	$6.75	n/a
Miami – South Region	$4.65	n/a	$4.85	n/a	$5.05	n/a
Average	$5.90	n/a	$6.10	n/a	$6.25	n/a
Total Average	$6.09					

Table A-II.20. Windows and insulation total cost, Δ $/100ft²/yr.

	Jacksonville Planform A	Orlando Planform A	Miami Planform A	Jacksonville Planform B	Orlando Planform B	Miami Planform B				
	Total Cost	Total Cost	Total Cost	Total Cost	Total Cost	Total Cost	Minimum	Maximum	Average	Average Deviation
SGL/LoE Metal Windows	35.02825	37.28814	40.11299	34.44444	36.66667	40.00000	34.44444	40.11299	37.25675	0.07607
SGL w/ Break Metal Windows	19.77401	16.94915	15.25424	19.25926	17.03704	15.55556	15.25424	19.77401	17.30488	0.13059
DBL/LoE/ARG Vinyl Windows	92.09040	83.61582	77.96610	89.62963	81.85185	77.77778	77.77778	92.09040	83.82193	0.08538
DBL/LoE Vinyl Windows	90.39548	82.48588	77.96610	88.14815	81.11111	77.77778	77.77778	90.39548	82.98075	0.07603
DBL/LoE/ARG Wood Windows	90.39548	82.48588	77.96610	88.14815	81.11111	77.77778	77.77778	90.39548	82.98075	0.07603
TRP Vinyl Windows	83.05085	70.62147	62.14689	80.37037	69.25926	62.59259	62.14689	83.05085	71.34024	0.14651
DBL/LoE Wood Windows	87.57062	80.22599	75.70621	122.59259	78.88889	75.55556	75.55556	122.59259	86.75664	0.27109
TRP Wood Windows	80.22599	68.36158	59.88701	77.77778	67.03704	60.37037	59.88701	80.22599	68.94329	0.14751
DBL Vinyl Windows	72.31638	59.88701	50.84746	69.62963	58.51852	51.48148	50.84746	72.31638	60.44675	0.17759
DBL Wood Windows	69.49153	57.62712	48.58757	67.03704	55.92593	49.25926	48.58757	69.49153	57.98807	0.18024
DBL/LoE/ARG w/ Break Windows	75.14124	67.23164	62.14689	73.33333	65.92593	62.22222	62.14689	75.14124	67.66688	0.09602
DBL/LoE w/ Break Windows	73.44633	66.66667	62.14689	71.48148	65.55556	62.22222	62.14689	73.44633	66.91986	0.08443
TRP w/ Break Metal Windows	64.97175	53.10734	44.06780	62.59259	51.85185	44.81481	44.06780	64.97175	53.56769	0.19512
DBL w/ Break Metal Windows	51.97740	40.11299	31.07345	49.62963	38.88889	31.48148	31.07345	51.97740	40.52731	0.25790
DBL Metal Windows	32.20339	22.59887	15.25424	30.74074	21.85185	15.92593	15.25424	32.20339	23.09584	0.36693
24in. Soffit Design	18.20988	23.76543	29.62963	15.76923	20.38462	25.76923	15.76923	29.62963	22.25467	0.31140
36in. Soffit Design	20.98765	30.45267	38.88889	18.71795	26.41026	34.35897	18.71795	38.88889	28.30273	0.35634
48in. Soffit Design	21.75926	32.71605	43.98148	19.80769	29.03846	38.65385	19.80769	43.98148	30.99280	0.38999
R-19 Batt, R-5 Cont., 2x6 Frame	2.69646	1.54083	0.77042	2.67574	1.58730	0.95238	0.77042	2.69646	1.70385	0.56520
R-19 Batt, 2x6 Frame	2.08012	1.15562	0.61633	2.04082	1.22449	0.72562	0.61633	2.08012	1.30717	0.55991
R-13 Batt, R-5 Cont., 2x4 Frame	1.92604	1.07858	0.53929	1.85941	1.08844	0.68027	0.53929	1.92604	1.19534	0.58007
R-11 Batt, R-5 Cont., 2x4 Frame	1.61787	0.92450	0.46225	1.58730	0.95238	0.54422	0.46225	1.61787	1.01475	0.56941
R-13 Batt, 2x4 Frame	0.77042	0.46225	0.23112	0.77098	0.45351	0.27211	0.23112	0.77098	0.49340	0.54707
R-7 Cont., CMU	2.00308	1.15562	0.53929	2.04082	1.22449	0.72562	0.53929	2.04082	1.28149	0.58585
R-25, 8" Ceiling	0.90278	0.62500	0.55556	0.58824	0.39216	0.49020	0.39216	0.90278	0.59232	0.43103
R-30, 10" Ceiling	1.45833	0.97222	0.83333	1.07843	0.68627	0.88235	0.68627	1.45833	0.98516	0.39185
R-35, 12" Ceiling	1.87500	1.25000	1.11111	1.27451	0.88235	1.07843	0.88235	1.87500	1.24523	0.39858
R-38, 12" Ceiling	2.08333	1.45833	1.25000	1.37255	0.98039	1.07843	0.98039	2.08333	1.37051	0.40238

Table A-II.21. HVAC total cost, Δ $/ea/yr/kHDD, kCDH.

Description	Total Cost	Total Cost	Total Cost	Total Cost	Total Cost	Total Cost	Minimum	Maximum	Average	Average Deviation
ASHP 8 HSPF/12 SEER HVAC	118.00	116.00	116.00	139.00	136.00	146.00	116.00	146.00	128.50	0.11673
ASHP 8 HSPF/14 SEER HVAC	180.00	189.00	189.00	210.00	220.00	250.00	180.00	250.00	206.33	0.16963
ASHP 9 HSPF/16 SEER HVAC	252.00	255.00	255.00	293.00	297.00	327.00	252.00	327.00	279.83	0.13401
GSHP 3.5 COP/16 EER HVAC	303.00	279.00	279.00	352.00	325.00	327.00	279.00	352.00	310.83	0.11743
GSHP 4.0 COP/18 EER HVAC	358.00	331.00	331.00	416.00	385.00	388.00	331.00	416.00	368.17	0.11544
Gas 90 AFUE/ 12 SEER HVAC	117.00	117.00	117.00	136.00	135.00	146.00	117.00	146.00	128.00	0.11328
Gas 90 AFUE/ 14 SEER HVAC	179.00	189.00	189.00	207.00	219.00	250.00	179.00	250.00	205.50	0.17275
Gas 95 AFUE/ 16 SEER HVAC	238.00	250.00	250.00	476.00	289.00	327.00	238.00	476.00	305.00	0.39016
Digital Programmable Thermostat	29.00	20.00	20.00	33.00	24.00	32.00	20.00	33.00	26.33	0.24684

Table A-II.22. Lighting, DHW, appliances and watergy total cost, Δ $/ea/yr. (watergy: no regional difference, total energy and water costs).

Description	Jacksonville Planform A	Orlando Planform A	Miami Planform A	Jacksonville Planform B	Orlando Planform B	Miami Planform B				
	Total Cost	Total Cost	Total Cost	Total Cost	Total Cost	Total Cost	Minimum	Maximum	Average	Average Deviation
Indoor Compact Fluorescent	1.85	1.85	2.00	3.17	3.11	3.29	1.857	3.29	2.55	0.28171
Electric Water Heat, R-5 Insulation	8.00	7.00	7.00	9.00	9.00	9.00	7.00	9.00	8.16	0.12245
Gas Instant Water Heat	46.00	44.00	43.00	47.00	45.00	43.00	43.00	47.00	44.66	0.04478
Gas Water Heat, R-5 Insulation	21.00	20.00	20.00	22.00	21.00	19.00	19.00	22.00	20.50	0.07317
Solar Water Heat	346.00	329.00	304.00	349.00	333.00	313.00	304.00	349.00	329.00	0.06839
Natural Gas Clothes Dryer	32.00	33.00	39.00	27.00	30.00	30.00	27.00	39.00	31.83	0.18848
Natural Gas Range-Oven	18.00	20.00	30.00	28.00	31.00	39.00	18.00	39.00	27.66	0.37952
High Efficiency Refrigerator	42.00	43.00	49.00	41.00	43.00	49.00	41.00	49.00	44.50	0.08989
Low-Flow Toilet Fixtures	n/a	n/a	n/a	n/a	n/a	n/a	48.56	60.47	54.51	0.11686
Low-Flow Shower Fixtures	n/a	n/a	n/a	n/a	n/a	n/a	64.51	75.86	70.19	0.08078
Low-Flow Sink\Lavatory Aerators	n/a	n/a	n/a	n/a	n/a	n/a	8.86	10.37	9.62	0.07852
Low-Flow Clothes Washer	n/a	n/a	n/a	n/a	n/a	n/a	43.80	52.35	48.58	0.07771
Low-Flow Dish Washer	n/a	n/a	n/a	n/a	n/a	n/a	106.80	112.98	109.89	0.02811

Table A-II.23. <10yr ROI integrated performance simulation, Δ MBtu, prioritized by SIR.

	Jacksonville, FL Planform A Item Unit Reduction (MBtu/yr)	Orlando, FL Planform A Item Unit Reduction (MBtu/yr)	Miami, FL Planform A Item Unit Reduction (MBtu/yr)	Jacksonville, FL Planform B Item Unit Reduction (MBtu/yr)	Orlando, FL Planform B Item Unit Reduction (MBtu/yr)	Miami, FL Planform B Item Unit Reduction (MBtu/yr)	Minimum	Maximum	Average	Average Deviation
Low-flow Shower Fixtures	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0%
Low-flow Toilet Fixtures	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0%
R-13 Batt Insulation, 2x4 Frame	0.02308	0.02308	0.02308	0.03182	0.01818	0.02138	0.01818	0.03182	0.02344	36%
Low-flow Dishwasher	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	0%
DBL/LoE/Vinyl Windows	3.38889	2.77778	2.77778	3.33333	3.07407	2.96296	2.77778	3.38889	3.05247	11%
Low-flow Clothes Washer	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0%
Natural Gas Range-Oven	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	0%
Programmable Thermostat	0.90000	0.80000	0.80000	0.90000	0.60000	0.90000	0.60000	0.90000	0.81667	10%
9 HSPF/16 SEER ASHP	7.30000	8.10000	8.10000	7.20000	7.80000	9.00000	7.20000	9.00000	7.91667	14%
Indoor Compact Fluorescent	0.06667	0.06667	0.06667	0.06667	0.06667	0.06667	0.06667	0.06667	0.06667	0%
Low-flow Sink/Lavatory Fixtures	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0%
Natural Gas Clothes Dryer	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	0%
High Efficiency Refrigerator	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0%
Solar DHW	7.50000	6.50000	6.50000	7.50000	7.00000	6.50000	6.50000	7.50000	6.91667	8%

Table A-II.24. <15yr ROI integrated performance simulation, Δ MBtu, prioritized by SIR.

	Jacksonville, FL Planform A Item Unit Reduction (MBtu/yr)	Orlando, FL Planform A Item Unit Reduction (MBtu/yr)	Miami, FL Planform A Item Unit Reduction (MBtu/yr)	Jacksonville, FL Planform B Item Unit Reduction (MBtu/yr)	Orlando, FL Planform B Item Unit Reduction (MBtu/yr)	Miami, FL Planform B Item Unit Reduction (MBtu/yr)	Minimum	Maximum	Average	Average Deviation
Low-flow Shower Fixtures	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0%
Low-flow Toilet Fixtures	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0%
R-13 Batt Insulation, 2x4 Frame	0.01538	0.02308	0.02308	0.03182	0.02010	0.02010	0.01538	0.03182	0.02226	43%
Low-flow Dishwasher	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	0%
DBL/LoE/Vinyl Windows	3.44444	2.77778	2.77778	3.33333	3.07407	2.96296	2.77778	3.44444	3.06173	12%
Low-flow Clothes Washer	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0%
Natural Gas Range-Oven	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	0%
Radiant Barrier	0.04778	0.04083	0.04083	0.06863	0.05882	0.06863	0.04083	0.06863	0.05425	26%
R-25, 8" Ceiling	0.02206	0.02083	0.02083	0.01961	0.00980	0.01961	0.00980	0.02206	0.01879	17%
Programmable Thermostat	0.70000	0.60000	0.60000	0.80000	0.60000	0.80000	0.60000	0.80000	0.68333	17%
9 HSPF/16 SEER ASHP	7.10000	8.00000	8.00000	6.90000	7.60000	8.70000	6.90000	8.70000	7.71667	13%
Indoor Compact Fluorescent	0.06667	0.06667	0.06667	0.07333	0.06667	0.06667	0.06667	0.07333	0.06778	8%
Low-flow Sink/Lavatory Fixtures	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0%
Natural Gas Clothes Dryer	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	0%
High Efficiency Refrigerator	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0%
Solar DHW	7.50000	6.50000	6.50000	7.50000	7.00000	6.50000	6.50000	7.50000	6.91667	8%

Table A-II.25. <20yr ROI integrated performance simulation, Δ MBtu, prioritized by SIR.

	Jacksonville, FL Planform A Item Unit Reduction (MBtu/yr)	Orlando, FL Planform A Item Unit Reduction (MBtu/yr)	Miami, FL Planform A Item Unit Reduction (MBtu/yr)	Jacksonville, FL Planform B Item Unit Reduction (MBtu/yr)	Orlando, FL Planform B Item Unit Reduction (MBtu/yr)	Miami, FL Planform B Item Unit Reduction (MBtu/yr)	Minimum	Maximum	Average	Average Deviation
Low-flow Shower Fixtures	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0%
Low-flow Toilet Fixtures	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0%
Low-flow Dishwasher	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	2.90000	0%
DBL/LoE/Vinyl Windows	3.38889	2.88889	2.88889	3.37037	3.07407	2.96296	2.88889	3.38889	3.09568	9%
Low-flow Clothes Washer	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0%
Natural Gas Range-Oven	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	-2.70000	0%
Radiant Barrier	0.04389	0.04389	0.04389	0.06863	0.06863	0.07843	0.04389	0.07843	0.05789	35%
Programmable Thermostat	0.80000	0.80000	0.80000	0.90000	0.60000	0.90000	0.60000	0.90000	0.80000	13%
R-19 Batt, 2x6	0.07692	0.04538	0.04538	0.07727	0.04545	0.04273	0.04273	0.07727	0.05552	39%
48 in. Soffit	1.05833	0.93846	0.93846	0.90385	1.32692	1.75000	0.90385	1.75000	1.15267	52%
9 HSPF/16 SEER ASHP	5.80000	5.70000	5.70000	4.70000	4.70000	5.20000	4.70000	5.80000	5.30000	9%
Indoor Compact Fluorescent	0.06667	0.06667	0.06667	0.06667	0.07333	0.07333	0.06667	0.07333	0.06889	6%
Low-flow Sink/Lavatory Fixtures	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0.03333	0%
R-38, 12" Ceiling	0.05556	0.03472	0.03472	0.02941	0.03064	0.03064	0.02941	0.05556	0.03595	55%
Natural Gas Clothes Dryer	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	-1.80000	0%
High Efficiency Refrigerator	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0.20000	0%
Solar DHW	7.50000	6.50000	6.50000	7.50000	7.00000	6.50000	6.50000	7.50000	6.91667	8%

INTEGRATED STRAIGHT-LINE ROI SIMULATION

Table A-II.26. <10yr ROI integrated straight-line ROI simulation, Δ$/item, prioritized by SIR.

	Jacksonville, FL Planform A Item Unit Cost Reduction ($/yr)	Orlando, FL Planform A Item Unit Cost Reduction ($/yr)	Miami, FL Planform A Item Unit Cost Reduction ($/yr)	Jacksonville, FL Planform B Item Unit Cost Reduction ($/yr)	Orlando, FL Planform B Item Unit Cost Reduction ($/yr)	Miami, FL Planform B Item Unit Cost Reduction ($/yr)	Minimum	Maximum	Average	Average Deviation
Low-flow Shower Fixtures	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	0%
Low-flow Toilet Fixtures	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0%
R-13 Batt Insulation, 2x4 Frame	$0.69	$0.54	$0.77	$0.77	$0.50	$0.59	$0.50	$0.77	$0.64	20%
Low-flow Dishwasher	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	0%
DBL/LoE/Vinyl Windows	$88.89	$80.00	$72.22	$88.15	$81.85	$77.78	$72.22	$88.89	$81.48	9%
Low-flow Clothes Washer	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	0%
Natural Gas Range-Oven	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	0%
Programmable Thermostat	$21.00	$17.00	$21.00	$22.00	$17.00	$23.00	$17.00	$23.00	$20.17	14%
9 HSPF/16 SEER ASHP	$195.00	$200.00	$215.00	$190.00	$205.00	$238.00	$190.00	$238.00	$207.17	15%
Indoor Compact Fluorescent	$1.73	$1.73	$1.73	$1.80	$1.80	$1.87	$1.73	$1.87	$1.78	5%
Low-flow Sink/Lavatory Fixtures	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	0%
Natural Gas Clothes Dryer	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	0%
High Efficiency Refrigerator	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	0%
Solar DHW	$202.50	$189.00	$175.00	$202.50	$189.00	$175.00	$175.00	$202.50	$188.83	7%

Table A-II.27. <15yr ROI integrated straight-line ROI simulation, Δ$/item, prioritized by SIR.

	Jacksonville, FL Planform A Item Unit Cost Reduction ($/yr)	Orlando, FL Planform A Item Unit Cost Reduction ($/yr)	Miami, FL Planform A Item Unit Cost Reduction ($/yr)	Jacksonville, FL Planform B Item Unit Cost Reduction ($/yr)	Orlando, FL Planform B Item Unit Cost Reduction ($/yr)	Miami, FL Planform B Item Unit Cost Reduction ($/yr)	Minimum	Maximum	Average	Average Deviation
Low-flow Shower Fixtures	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	0%
Low-flow Toilet Fixtures	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0%
R-13 Batt Insulation, 2x4 Frame	$0.69	$0.54	$0.77	$0.77	$0.50	$0.59	$0.50	$0.77	$0.64	20%
Low-flow Dishwasher	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	0%
DBL/LoE/Vinyl Windows	$88.89	$80.00	$72.22	$88.15	$81.11	$77.78	$72.22	$88.89	$81.36	9%
Low-flow Clothes Washer	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	0%
Natural Gas Range-Oven	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	0%
Radiant Barrier	$1.69	$1.49	$1.56	$1.76	$1.57	$1.76	$1.49	$1.76	$1.64	8%
R-25, 8" Ceiling	$0.57	$0.69	$0.56	$0.49	$0.57	$0.57	$0.49	$0.69	$0.58	21%
Programmable Thermostat	$20.00	$15.00	$17.00	$22.00	$16.00	$21.00	$15.00	$22.00	$18.50	19%
9 HSPF/16 SEER ASHP	$186.00	$194.00	$211.00	$181.00	$199.00	$230.00	$181.00	$230.00	$200.17	15%
Indoor Compact Fluorescent	$1.80	$1.73	$1.73	$1.87	$1.80	$1.87	$1.73	$1.87	$1.80	4%
Low-flow Sink/Lavatory Fixtures	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	0%
Natural Gas Clothes Dryer	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	0%
High Efficiency Refrigerator	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	0%
Solar DHW	$202.50	$189.00	$175.00	$202.50	$189.00	$175.00	$175.00	$202.50	$188.83	7%

Table A-II.28. <20yr ROI integrated straight-line ROI simulation, Δ$/item, prioritized by SIR.

	Jacksonville, FL Planform A Item Unit Cost Reduction ($/yr)	Orlando, FL Planform A Item Unit Cost Reduction ($/yr)	Miami, FL Planform A Item Unit Cost Reduction ($/yr)	Jacksonville, FL Planform B Item Unit Cost Reduction ($/yr)	Orlando, FL Planform B Item Unit Cost Reduction ($/yr)	Miami, FL Planform B Item Unit Cost Reduction ($/yr)	Minimum	Maximum	Average	Average Deviation
Low-flow Shower Fixtures	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	0%
Low-flow Toilet Fixtures	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	0%
Low-flow Dishwasher	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	$78.30	0%
DBL/LoE/Vinyl Windows	$87.78	$80.56	$76.11	$88.15	$81.11	$77.78	$76.11	$88.15	$81.91	8%
Low-flow Clothes Washer	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	$18.90	0%
Natural Gas Range-Oven	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	0%
Radiant Barrier	$1.42	$1.35	$1.42	$1.96	$1.86	$2.06	$1.35	$2.06	$1.68	23%
Programmable Thermostat	$23.00	$18.00	$21.00	$23.00	$16.00	$22.00	$16.00	$23.00	$20.50	12%
R-19 Batt, 2x6	$2.00	$1.23	$1.23	$1.77	$1.18	$1.23	$1.18	$2.00	$1.44	39%
48 in. Soffit	$22.77	$28.77	$34.46	$23.65	$34.81	$45.96	$22.77	$45.96	$31.74	45%
9 HSPF/16 SEER ASHP	$154.00	$147.00	$151.00	$155.00	$125.00	$137.00	$125.00	$155.00	$144.83	7%
Indoor Compact Fluorescent	$1.67	$1.67	$1.80	$1.80	$1.80	$1.87	$1.67	$1.87	$1.77	6%
Low-flow Sink/Lavatory Fixtures	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	$0.90	0%
R-38, 12" Ceiling	$1.06	$1.04	$0.83	$0.69	$0.79	$0.79	$0.69	$1.06	$0.87	22%
Natural Gas Clothes Dryer	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	$22.00	0%
High Efficiency Refrigerator	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	0%
Solar DHW	$202.50	$189.00	$175.00	$202.50	$189.00	$175.00	$175.00	$202.50	$188.83	7%

APPENDIX III
MARKET SURVEY ASSESSMENT DATA ANALYSIS

Table A-III.1. Frequency distribution of survey population.

Region	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Duval	40	10%	40	10%
Orange	38	10%	78	20%
Seminole	18	5%	96	25%
Broward	90	22%	186	47%
Dade	93	23%	279	70%
Palm Beach	119	30%	398	100%

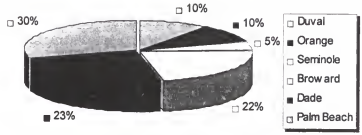


Figure A-III.1. Frequency distribution of survey population.

Table A-III.2. Homeowner satisfaction with current residence.

Question 1: Overall, how satisfied are you with your current home?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Refused	1	0.4%	1	0.4%
Very Satisfied	272	68.2%	273	68.6%
Satisfied	106	26.6%	379	95.1%
Neither	5	1.3%	384	96.4%
Unsatisfied	10	2.5%	394	98.9%
Very Unsatisfied	4	1.0%	398	99.9%
Don't Know	1	0.3%	399	100.2%

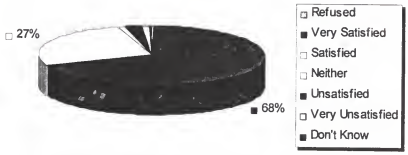


Figure A-III.2. Homeowner satisfaction with current residence.

Table A-III.3. Factors influencing decision to purchase.

Question 2: ...factors that may affect your decision to purchase?	Security	Aesthetics	Location	Cost
Very Important	60.7%	69.3%	75.2%	70.2%
Important	31.6%	32.6%	21.3%	19.3%
Neither	3.8%	2.0%	1.3%	6.8%
Unimportant	1.3%	0.8%	0.5%	1.8%
Very Important	1.3%	0.8%	1.5%	1.8%

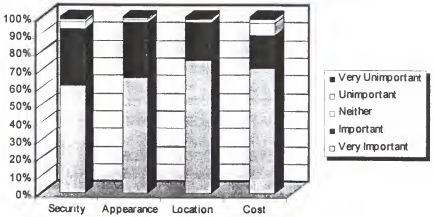


Figure A-III.3. Factors influencing decision to purchase.

Table A-III.4. Cost factors influencing decision to purchase.

Question 3: ... cost factors that may affect your decision to purchase?	Total Costs	Interest Rates	Resale Value	Monthly Costs
Very Important	64.3%	56.3%	58.8%	65.6%
Important	23.9%	25.4%	25.1%	15.5%
Neither	0.5%	3.0%	2.3%	3.4%
Unimportant	0.5%	1.3%	1.0%	0.3%
Very Important	0.3%	3.0%	1.8%	4.3%

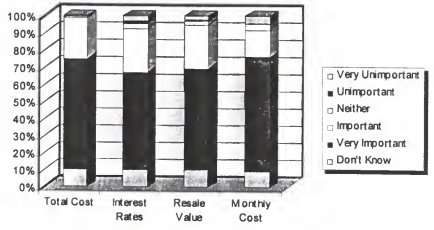


Figure A-III.4. Cost factors influencing decision to purchase.

Table A-III.5. Distriution of owner-occupants having low-flow water fixtures.

Question 4a: Does your home have low-flow water fixtures?	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes	274	68.7%	274	70.9%
No	103	25.8%	377	94.4%
Don't Know	22	5.5%	399	100.0%

Figure A-III.5. Distribution of owner-occupants having low-flow water fixtures.

Table A-III.6. Perception of cost savings using low-flow water fixtures.

Question 4c, 4d: How much do you perceive costs vs. savings per month?	**COSTS**			**SAVINGS**		
	-$20.00+	**-$10.00**	**$0.00**	**$0.00**	**$10.00**	**$20.00+**
	6%	14%	42%	33%	12%	24%

* "Refused" or "Don't Know" responses accountable for remaining sum of 100.0%

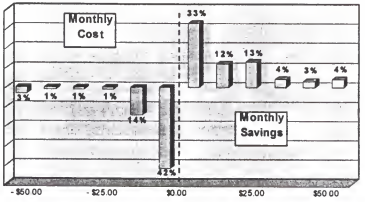


Figure A-III.6. Perception of cost savings using low-flow water fixtures.

Table A-III.7. Distriution of owner-occupants having high-efficiency HVAC systems.

Question 5a: Does your home have a high-efficiency HVAC system?	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
Yes	299	74.9%	299	76.2%
No	59	14.8%	358	88.9%
Don't Know	41	10.3%	399	100.0%

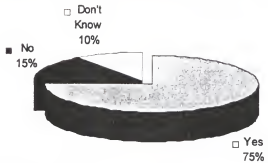


Figure A-III.7. Distribution of owner-occupants having high-efficiency HVAC systems.

Table A-III.8. Perception of cost savings using high-efficiency HVAC systems.

Question 5c, 5d: How much do you perceive costs vs. savings per month?	**COSTS**			**SAVINGS**		
	-$20.00+	**-$10.00**	**$0.00**	**$0.00**	**$10.00**	**$20.00+**
	9%	12%	37%	24%	19%	25%

* "Refused" or "Don't Know" responses accountable for remaining sum of 100.0%

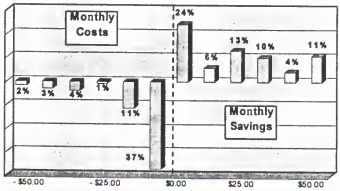


Figure A-III.8. Perception of cost savings using high-efficiency HVAC systems.

Table A-III.9. Willingness-to-pay for low cost, low return; moderate cost, moderate return; and high cost, high return sustainable alternatives.

Question 6a: Which sustainable option would you be most likely to purchase?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Single-pane, tinted*	117	29.3%	117	18.0%
Single-pane, LoE reflective**	84	21.1%	152	38.1%
Double-pane, LoE reflective***	153	38.3%	345	86.5%
None	24	6.0%	376	94.2%
Don't Know	21	5.3%	399	100.0%

Question 6b: Which sustainable option would you be most likely to purchase?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Low-flow shower and sink*	72	18.0%	72	18.0%
Low-flow shower, sink and toilet**	80	20.1%	152	38.1%
Low-flow shower, toilet, appliances***	193	48.4%	345	86.5%
None	31	7.8%	376	94.2%
Don't Know	21	5.8%	399	100.0%

Question 6c: Which sustainable option would you be most likely to purchase?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
12 SEER ASHP*	71	17.8%	71	17.8%
14 SEER ASHP**	136	34.1%	207	51.9%
16 SEER ASHP***	152	38.1%	359	90.0%
None	18	4.5%	377	94.5%
Don't Know	22	5.5%	399	100.0%

* Low capital cost, low life-cycle return-on-investment
** Moderate capital cost, moderate life-cycle return-on-investment
*** High capital cost, high life-cycle return-on-investment

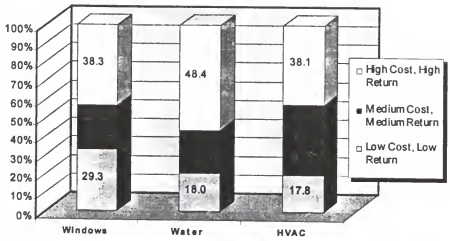


Figure A-III.9. Willingness-to-pay for low, moderate and high cost, high return alternatives.

Table A-III.10. Willingness-to-pay or soft cost benefits.

Question 7a: Solar…willingness-to-pay for regardless of future *monetary* savings?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Very Likely	67	16.8%	67	16.8%
Likely	104	26.1%	171	42.9%
Neither	43	10.8%	214	53.6%
Unlikely	53	13.3%	267	66.9%
Very Unlikely	113	28.3%	380	95.2%

Question 7b: Fuel Cells…willingness-to-pay for regardless of *monetary* savings?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Very Likely	56	14.0%	56	14.0%
Likely	79	19.8%	135	33.8%
Neither	51	12.8%	186	46.6%
Unlikely	48	12.0%	234	58.6%
Very Unlikely	141	35.3%	375	94.0%

Question 7c: Ultra-efficient HVAC… willingness-to-pay regardless of savings?	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Very Likely	121	30.3%	121	30.3%
Likely	123	30.8%	244	61.2%
Neither	46	11.5%	290	72.7%
Unlikely	27	6.8%	317	79.4%
Very Unlikely	61	15.3%	378	94.7%

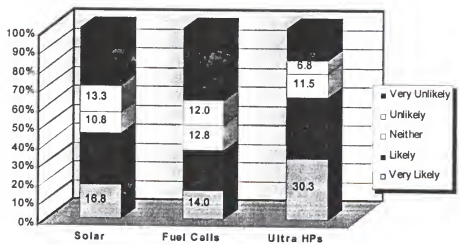


Figure A-III.10. Willingness-to-pay for soft cost benefits.

Table A-III.11. Gender distribution of survey population.

Question 8: Gender	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Male	201	50.4%	201	50.4%
Female	198	49.6%	399	100.0%

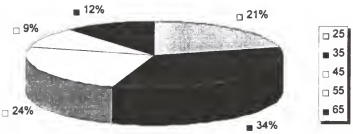


Figure A-III.11. Age distribution of survey population.

Table A-III.12. Age distribution of survey population.

Question 9: Age	Frequency	Percent	Cumulative Frequency	Cumulative Percent
<25-	75	21.2%	75	21.2%
35-	120	34.0%	195	55.2%
45-	83	23.5%	278	78.7%
55-	34	9.6%	312	88.3%
65+	41	11.6%	353	100.0%

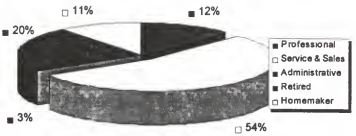


Figure A-III.12. Occupation distribution of survey population.

Table A-III.13. Occupation distribution of survey population.

Question 10: Occupation	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Professional	32	12.2%	32	12.2%
Service & Sales	141	53.6%	173	65.8%
Administrative & Secretarial	8	3.0%	181	68.8%
Retired	53	20.2%	234	89.0%
Homemaker	29	11.0%	263	100.0%

Table A-III.14. Income distribution of survey population.

Question 11: Income	Frequency	Percent	Cumulative Frequency	Cumulative Percent
< $20,000	7	4.3%	7	4.3%
$20,000 - $34,999	16	9.8%	23	14.1%
$35,000 - $49,999	47	28.8%	70	43.0%
$50,000 - $69,999	39	23.9%	109	66.9%
> $69,999	54	33.1%	163	100.0%

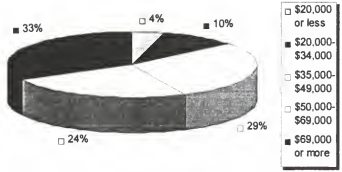


Figure A-III.13. Income distribution of survey population.

Table A-III.15. Race and ethnicity distribution of survey population.

Question 12: Race & Ethnicity	Frequency	Percent	Cumulative Frequency	Cumulative Percent
White	310	77.7%	310	93.7%
Black	22	5.5%	332	99.2%
Asian	6	1.5%	338	100.7%
White (Hispanic)	55	13.8%	55	13.8%
White (Non-Hispanic)	319	79.9%	374	93.7%

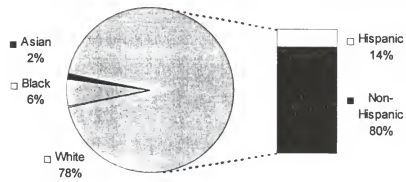


Figure A-III.14. Race and ethnicity distribution of survey population.

Table A-III.16. Response rates per region and classification of non-response.

	Four Attempts	Refusal	Language Barrier	Non-Working	Business	Misc	Complete
North Region							
Duval	55 (30%)	40 (22%)	10 (6%)	15 (8%)	0 (0%)	20 (12%)	40 (22%)
Subtotal	55 (30%)	40 (22%)	10 (6%)	15 (8%)	0 (0%)	20 (12%)	40 (22%)
Central Region							
Orange	27 (20%)	44 (33%)	3 (2%)	11 (8%)	0 (0%)	11 (8%)	38 (29%)
Seminole	10 (12%)	25 (33%)	2 (3%)	10 (12%)	0 (0%)	12 (16%)	18 (24%)
Subtotal	37 (17%)	69 (33%)	5 (2%)	21 (10%)	0 (0%)	23 (12%)	56 (27%)
South Region							
Broward	90 (28%)	95 (29%)	15 (4%)	10 (3%)	5 (2%)	22 (7%)	90 (28%)
Palm Beach	85 (16%)	198(37%)	45 (9%)	20 (4%)	15 (3%)	45 (9%)	119 (23%)
Dade	15 (4%)	110 (32%)	90 (26%)	10 (3%)	5 (2%)	15 (4%)	95 (28%)
Subtotal	190 (16%)	403 (34%)	150 (13%)	40 (3%)	20 (2%)	82 (7%)	304 (26%)
Total	**282 (18%)**	**512 (32%)**	**165 (10%)**	76 **(5%)**	**20 (1%)**	**125 (8%)**	**400 (26%)**

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BIOGRAPHICAL SKETCH

Kevin R. Grosskopf was born in St. Petersburg, Florida, on the 12th day of September, 1968 to Roy E. Grosskopf and Margaret L. Grosskopf. He graduated Northside Christian High School on June 6th, 1986 and received the degree of Associate in Arts from St. Petersburg Junior College three years later. On April 24th, 1992, Kevin R. Grosskopf was awarded the Degree of Bachelor of Science in Construction Engineering Technology from the Florida Agricultural and Mechanical University with the honor of Summa Cum Laude.

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I certify that I have read this study and that it is my opinion it conforms to the acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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December 1998

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